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(54) **TIME-DEPENDENT MACHINE-GENERATED HINTING**

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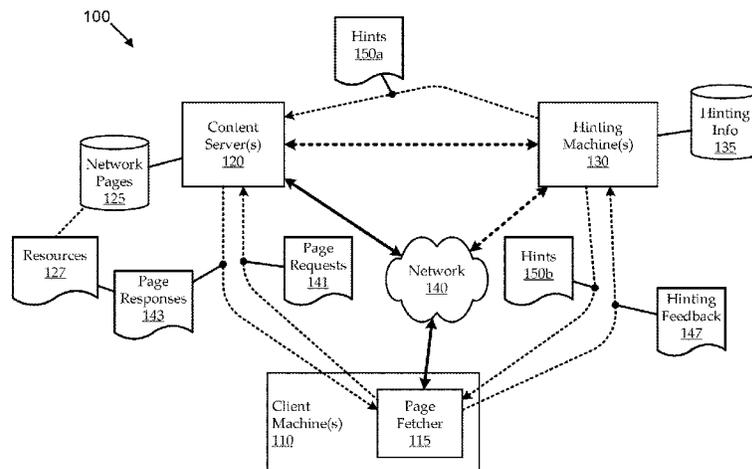
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(57) **ABSTRACT**

Embodiments seek to improve prefetch hinting using time-dependent, machine-generated hints. Some embodiments operate in context of client machines in communication hinting machines that can develop information about whether and how resources are used in network transactions over time by collecting "resource samples." Each resource sample can identify rendering status information of a resource at a sample time. The time-based samples can be used to compute time-based probabilities for the resources, indicating, for example, the likelihood of a resource being used to render a web page at some subsequent time. Time-dependent hints can be generated as a function of the time-based probabilities, and the time-dependent hints can be used to improve prefetching by optimizing the hinting information with respect to a particular request time (e.g., the prefetching hints for rendering a web page can be generated in a manner that accounts for when the web page is being rendered).

**39 Claims, 11 Drawing Sheets**



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CPC ..... **G06F 16/9574** (2019.01); **G06F 16/986** (2019.01); **H04L 67/5681** (2022.05)

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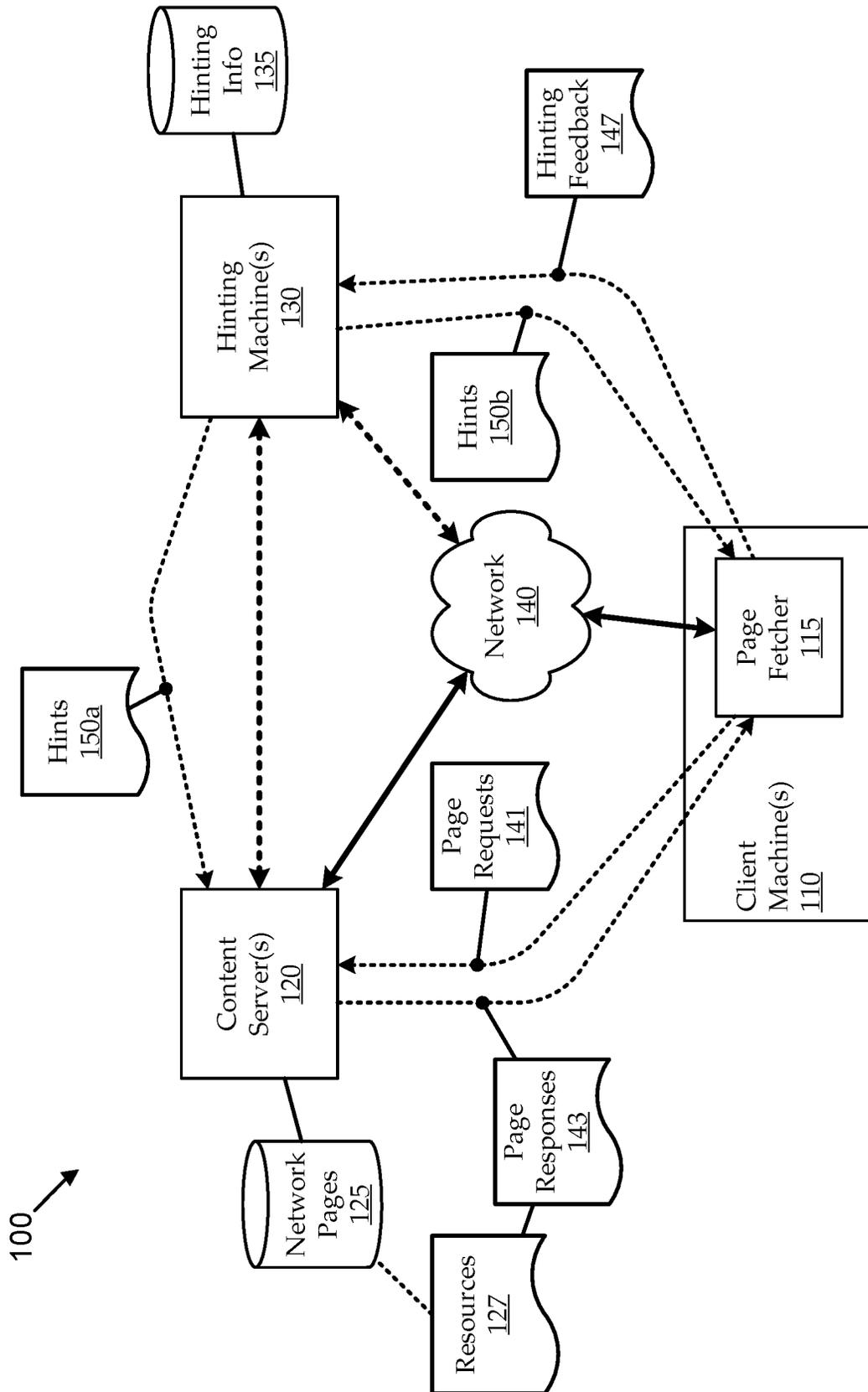


FIG. 1

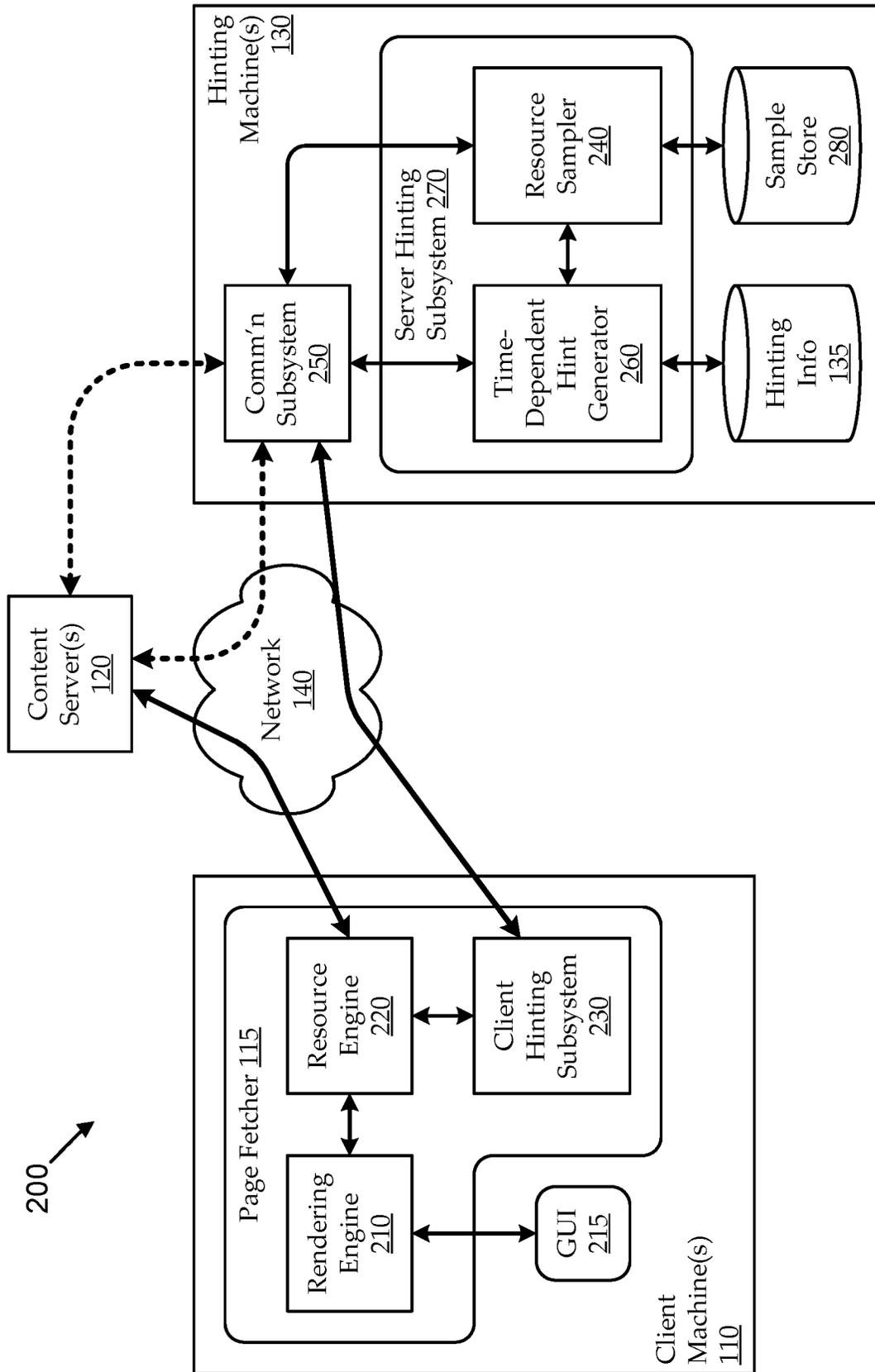


FIG. 2A

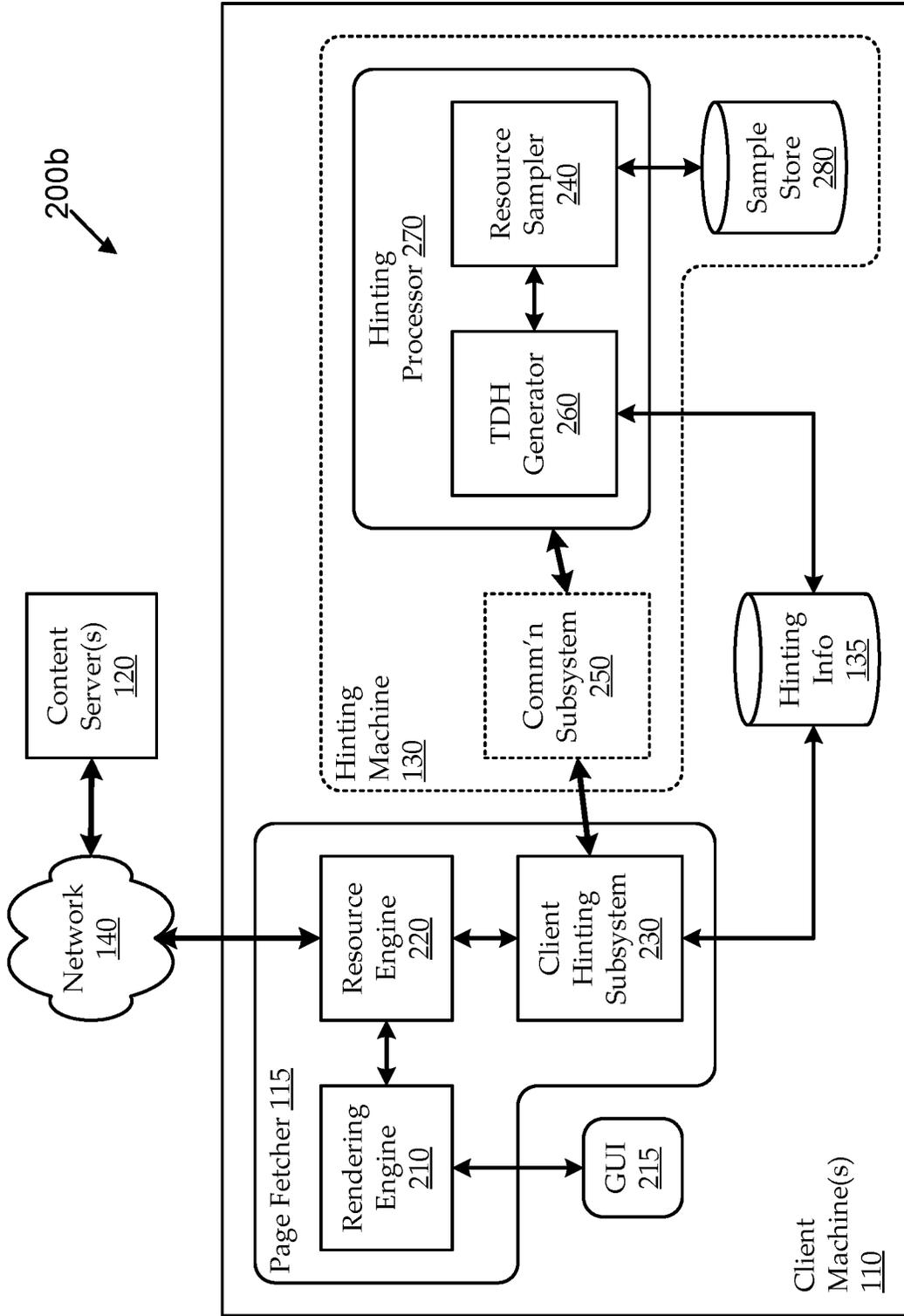
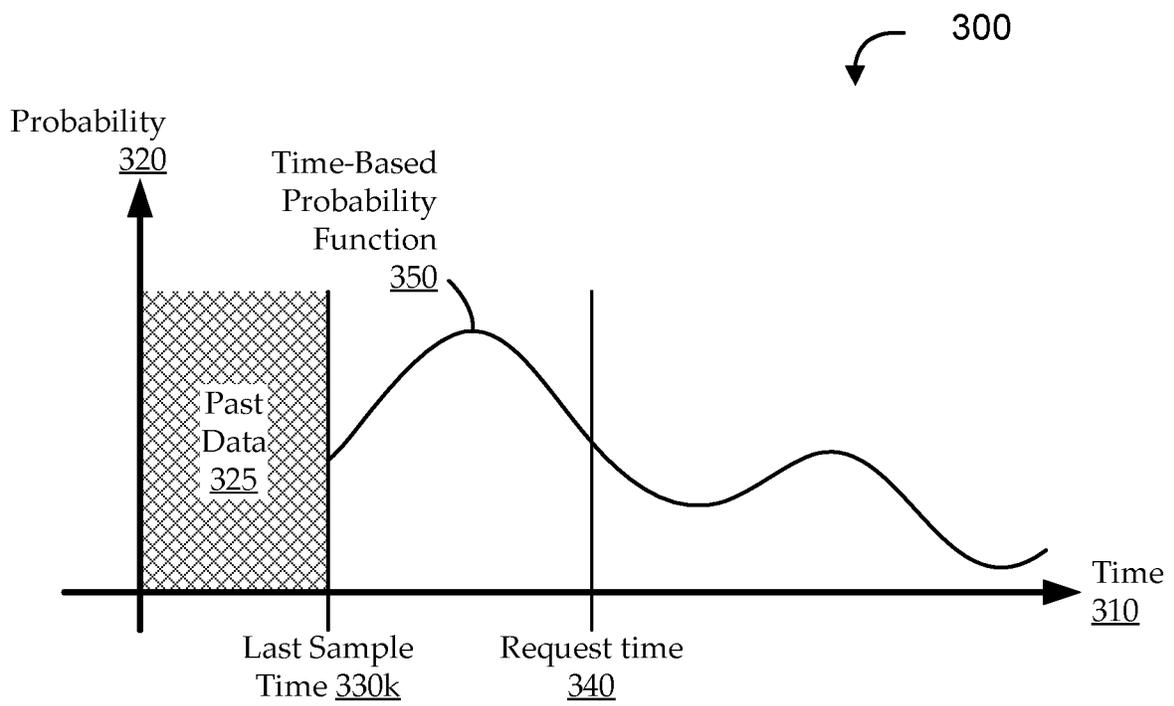


FIG. 2B



**FIG. 3**

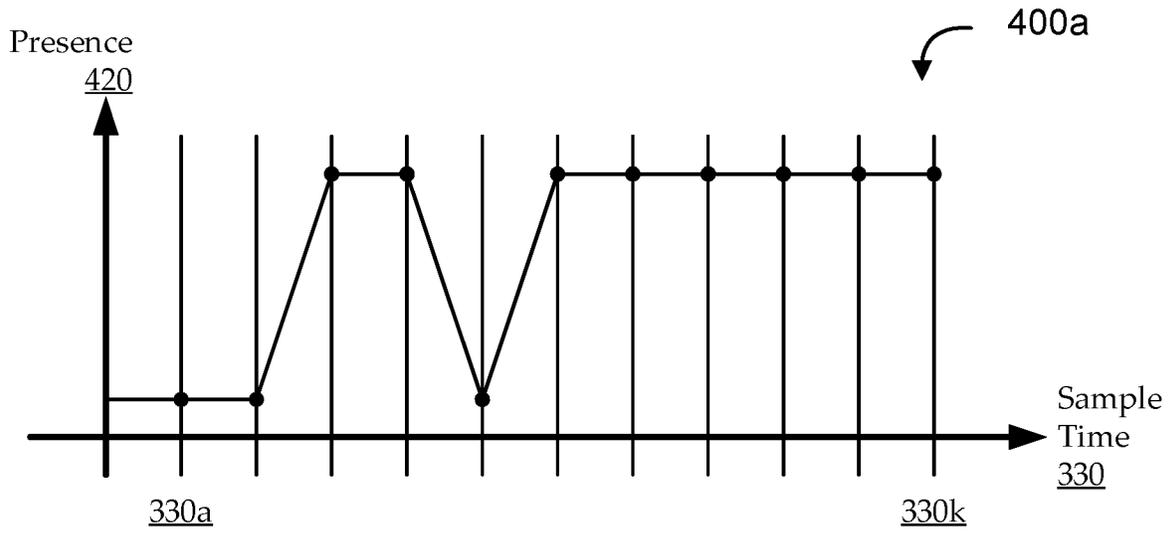


FIG. 4A

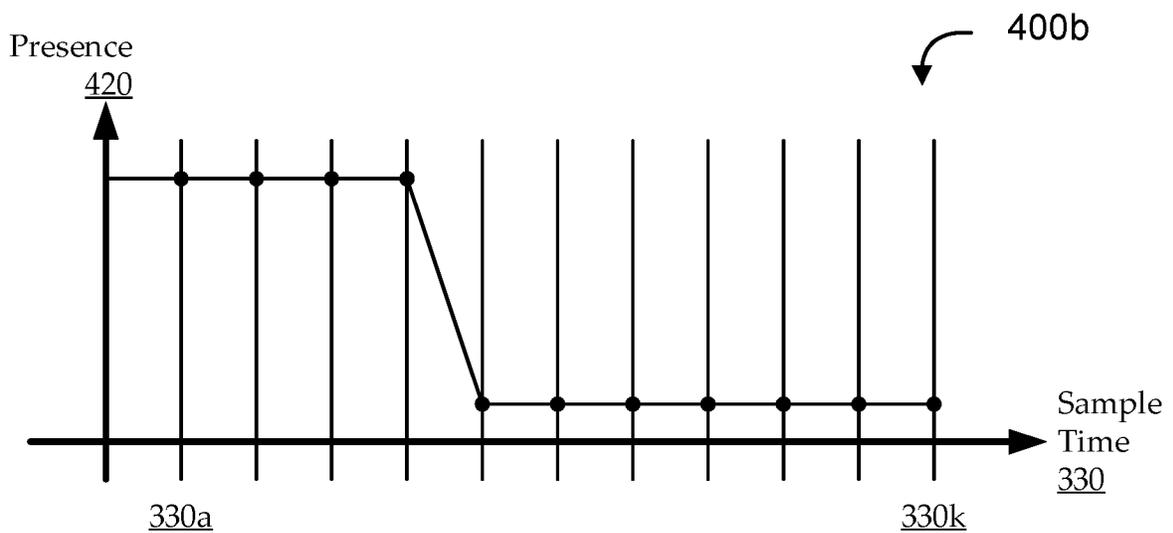


FIG. 4B

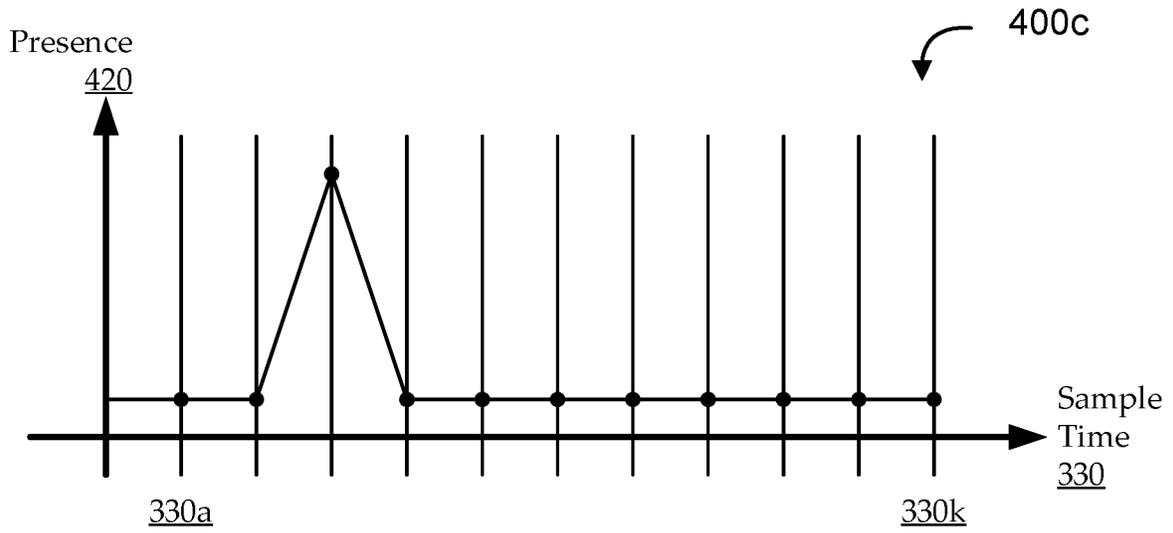


FIG. 4C

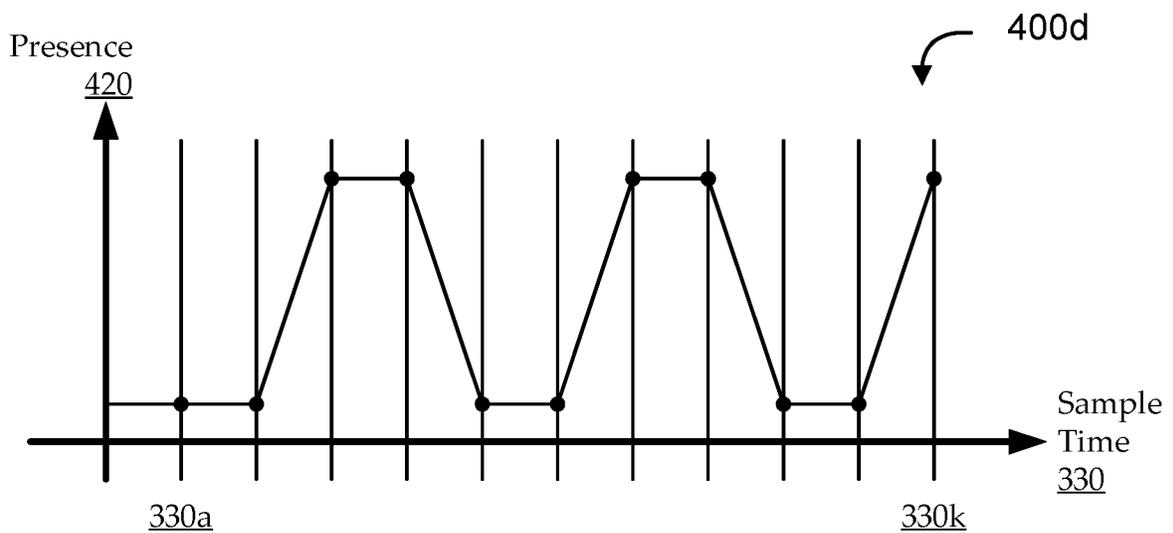


FIG. 4D

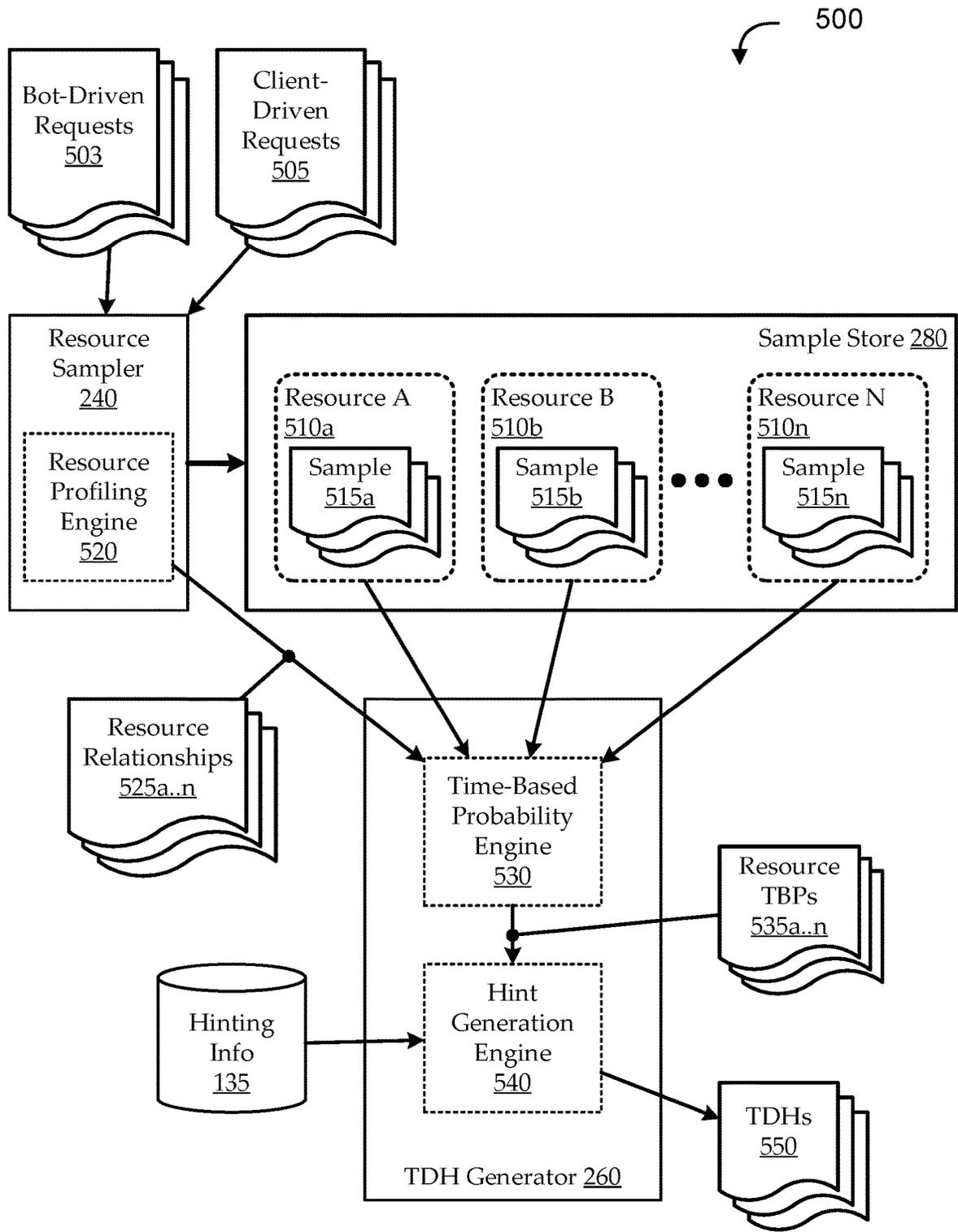
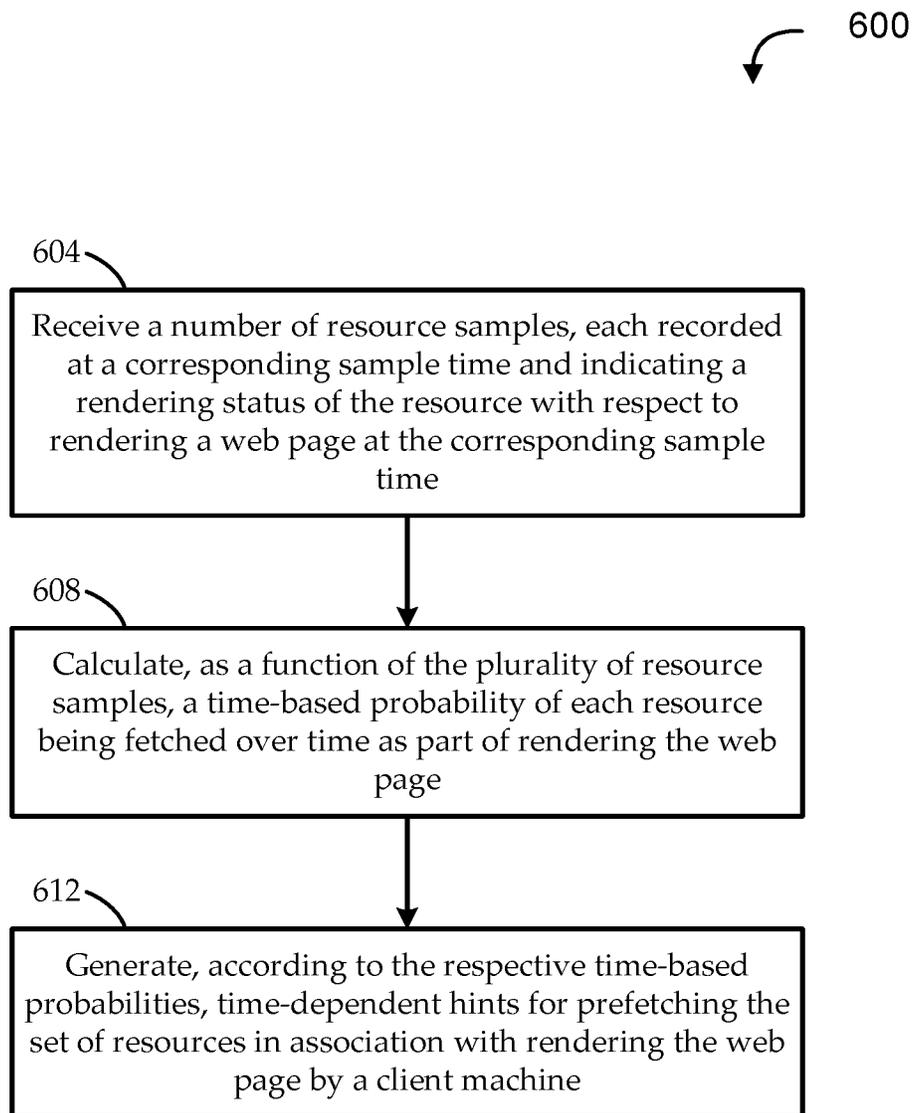


FIG. 5

**FIG. 6**

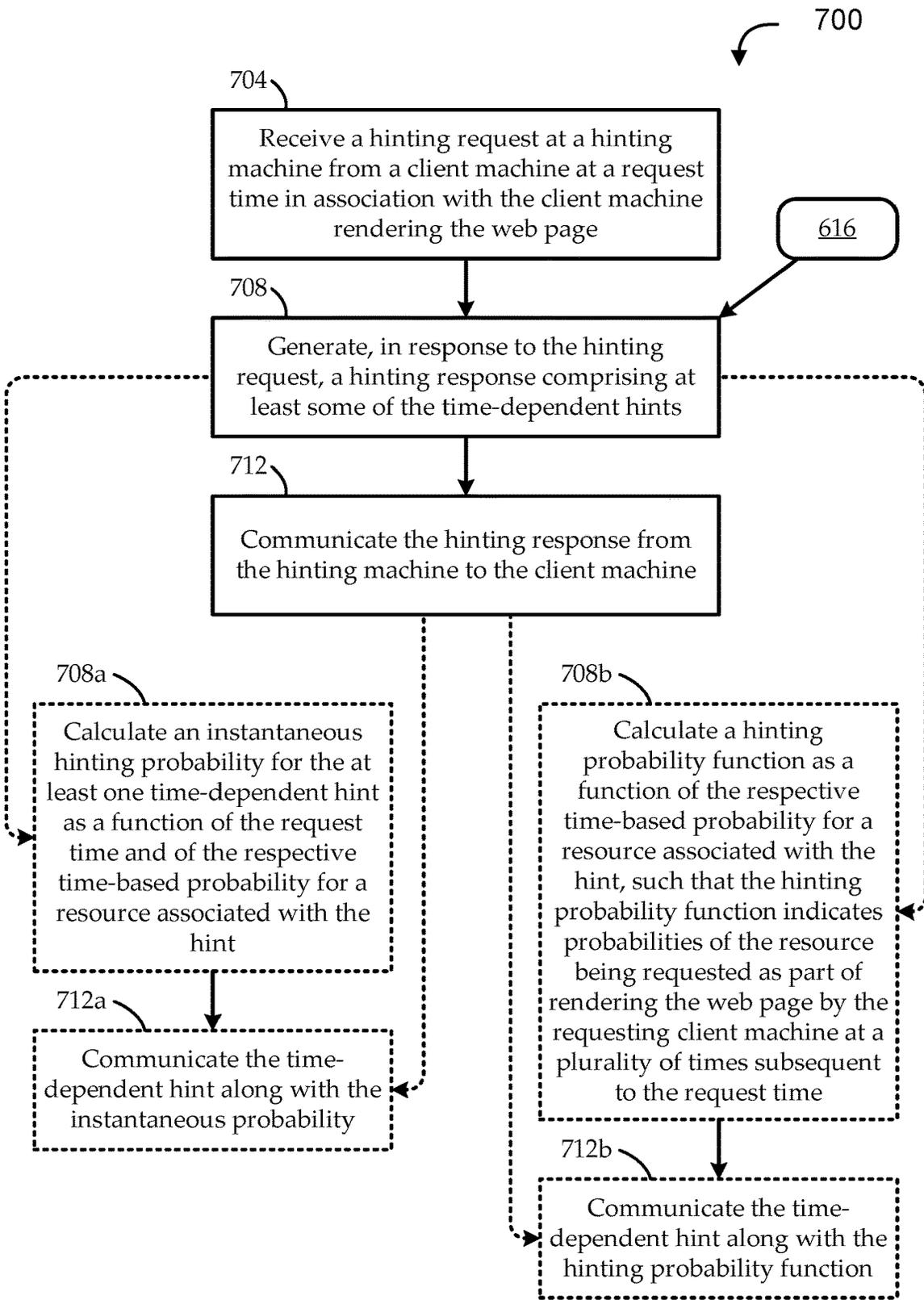


FIG. 7

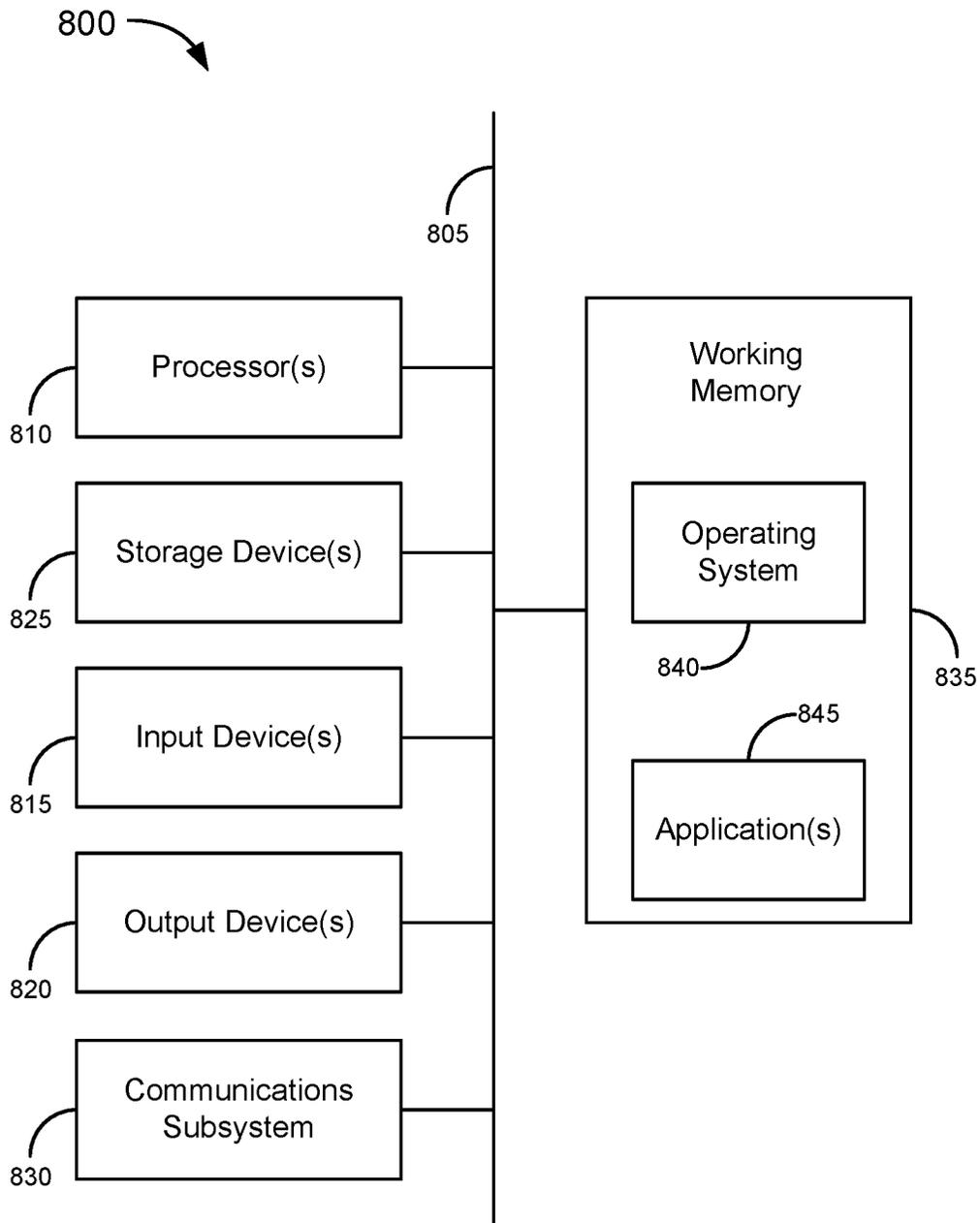


FIG. 8

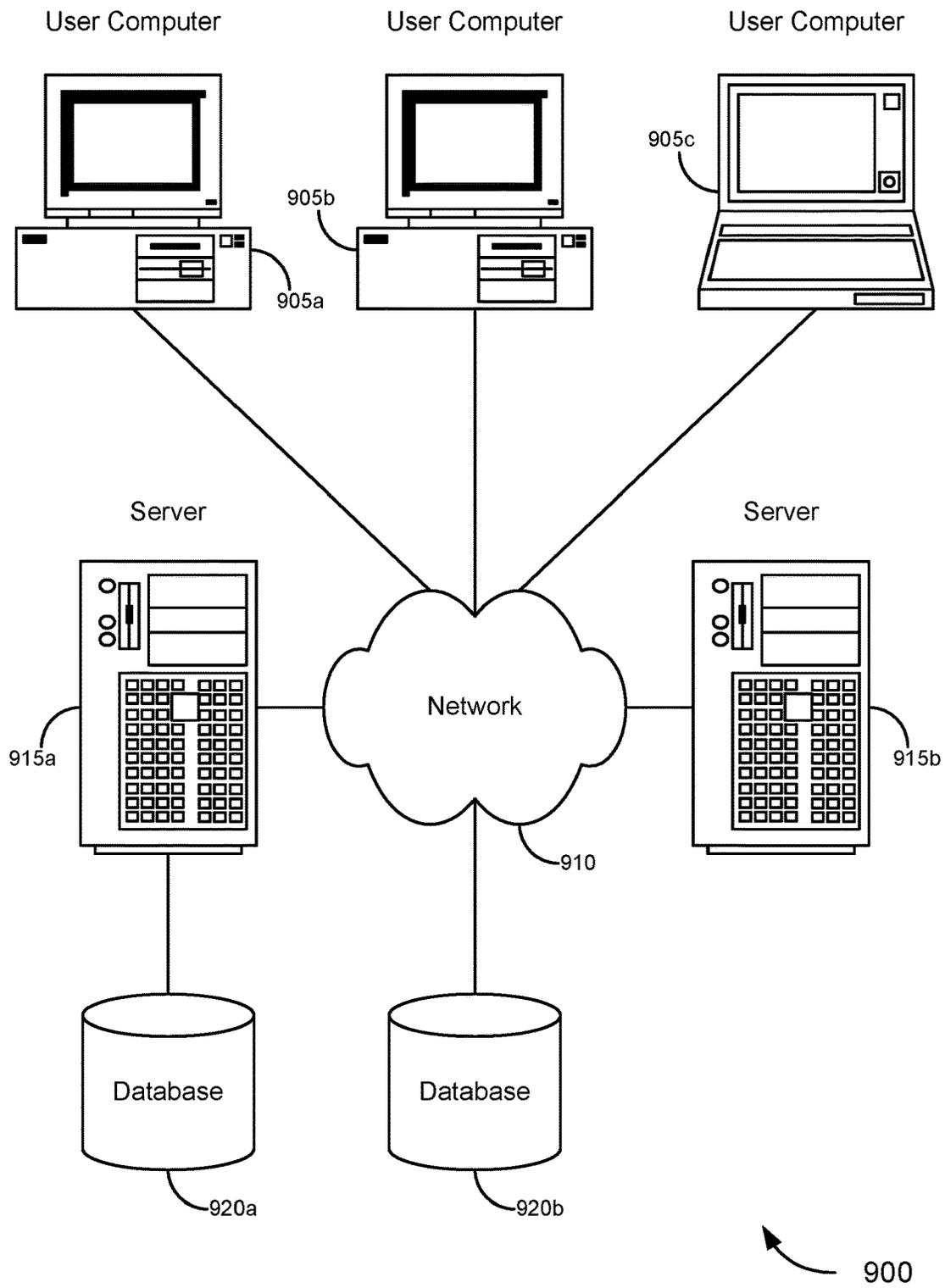


FIG. 9

## TIME-DEPENDENT MACHINE-GENERATED HINTING

### CROSS-REFERENCE TO RELATED APPLICATIONS

This application is a continuation of U.S. application Ser. No. 15/962,927 filed Apr. 25, 2018 and entitled “TIME-DEPENDENT MACHINE-GENERATED HINTING,” which is a continuation of PCT App. No. PCT/US2015/057847 filed Oct. 28, 2015, each of which is expressly incorporated by reference herein in its entirety for all purposes.

### FIELD

Embodiments relate generally to network communications performance, and, more particularly, to time-dependent, machine-driven hint generation.

### BACKGROUND

Web page transmission, in which a user selects web page content and receives objects, is a core part of the Internet experience for Internet users. While the experience of users is typically a single selection followed by the viewing of a web page that is presented on the screen, the process of presenting the web page on the screen can involve a large number of resources (e.g., page objects) and multiple request/response round-trip communications from the user system to one or more web servers that are providing resources for the web page. Additionally, each resource may be associated with a number of different phases as part of the inclusion of the resource (or an object associated with the resource) in a web page that is presented to a user. Each resource that is part of a web page and each phase associated with each resource may contribute to an overall page load time that is experienced by a device user as delay. Various techniques permit information to be sent to browsers regarding the resources used to render a web page (“hints”), and the browsers can use those hints to improve the loading time for that web page.

### BRIEF SUMMARY

Among other things, systems and methods are described for improving prefetch hinting using time-dependent, machine-generated hints. Some embodiments operate in context of client machines having page fetchers (e.g., implemented in web browsers) in communication (e.g., over a communications network) with content servers and hinting machines. The hinting machines can develop information about whether and how resources are used in network transactions (e.g., to render web pages) over time by collecting “resource samples.” The samples can be collected as part of receiving hinting requests from client machines, as part of receiving hinting feedback from client machines, as information monitored and/or generated during automated crawling of web pages, and/or in any other suitable manner. Each resource sample can identify rendering status information of the resource at the time the sample was collected (i.e., the sample time). For example, the resource sample can identify whether the resource was loaded as part of rendering a web page, when the resource was loaded in context of other resources on the page, and/or any other information describing whether and how the resource was loaded in relation to rendering the web page at the sample time.

In such contexts, where the resource samples correspond to particular sample times, the resource samples can be considered as “time-based samples.” The time-based samples can be used to compute time-based probabilities for the resources (e.g., as instantaneous probabilities at a particular time, as probability functions over time, etc.). Such probabilities can indicate, for example, the likelihood of a resource being used to render a web page at some subsequent time, and can be used to generate time-dependent hints. In some implementations, the time-dependent hints can be used to improve prefetching by optimizing the hinting information with respect to a particular request time (i.e., the hints are generated in a manner that accounts for when the web page is being rendered). In other implementations, the time-dependent hints can permit client machines to generate their own hints on demand, even when access to a hinting machine is unavailable (and/or external hinting information is otherwise unavailable). For example, embodiments can receive a hinting request at a request time, and generate and communicate time-dependent hints based on the time-based probabilities and the request time. Other implementations and features involving time-dependent hints are described more fully herein.

### BRIEF DESCRIPTION OF THE DRAWINGS

The present disclosure is described in conjunction with the appended figures:

FIG. 1 shows an illustrative communications system environment that provides a context for various embodiments;

FIG. 2A shows a block diagram of a portion of an illustrative communications environment for implementing time-dependent hint generation, according to various embodiments;

FIG. 2B shows a block diagram of a portion of another illustrative communications environment for implementing time-dependent hint generation, according to various embodiments;

FIG. 3 shows an example graph of a time-based probability function for an illustrative resource;

FIGS. 4A-4D show graphical plots of sets of resource samples that can be fit into illustrative types of presence models;

FIG. 5 shows an illustrative system for implementing a data flow, according to various embodiments;

FIG. 6 shows a flow diagram of an illustrative method for time-dependent machine-generation of hints, according to various embodiments;

FIG. 7 shows a flow diagram of another method for time-dependent hinting, according to various embodiments;

FIG. 8 provides a schematic illustration of one embodiment of a computer system that can perform the methods of the invention, as described herein, and/or can function, for example, as any part of client machine(s), content server(s), hinting machine(s) 130 or any other such computer or device; and

FIG. 9 illustrates a schematic diagram of a network system that can be used in accordance with one set of embodiments.

In the appended figures, similar components and/or features can have the same reference label. Further, various components of the same type can be distinguished by following the reference label by a second label that distinguishes among the similar components. If only the first reference label is used in the specification, the description is

applicable to any one of the similar components having the same first reference label irrespective of the second reference label.

#### DETAILED DESCRIPTION

In the following description, numerous specific details are set forth to provide a thorough understanding of the present invention. However, one having ordinary skill in the art should recognize that the invention can be practiced without these specific details. In some instances, circuits, structures, and techniques have not been shown in detail to avoid obscuring the present invention.

Embodiments operate in context of machine-driven hint generation that provides time-dependent hints based on accumulated resource samples collected over time from one or more “client” machines. As used herein, a “client” or “client machine” is generally intended to include any computational platform involved in a web transaction, such as rendering a web page, and is not intended to be limited to any particular network architecture, protocol, etc. For example, in some implementations, a client machine can interact with a server machine (e.g., a hinting machine) in a “client-server” context, such as a client-server architecture using client-server types of protocols. Other implementations can operate in a peer-to-peer context, or any other suitable context. In such contexts, a particular machine can act as a client for a particular transaction, and as a server or other function in other transactions (e.g., the same machine can operate as a “client” for one transaction and as a server for another transaction, according to peer-to-peer and/or other protocols).

As used herein, “web page transaction” generally refers to a communication between a client machine and another machine (e.g., a server computer) to transfer a plurality of objects to the client machine which may be presented to a user as part of a web page. As used herein, a “web page” is intended to broadly refer to any type of page sent over a communications network and consisting of multiple page resources. For example, the web page can be a typical web page used in World Wide Web communications, a page (e.g., screen) of an application (e.g., an app, etc.), or any other type of web page. Further, reference to “web” is not intended to be limited to the Internet or the World Wide Web; rather, the “web” can include any public or private communications network. Further, terms like “page fetcher,” “page renderer,” or “page loader,” as used herein, are not intended to be limited to any particular process in a web browser; rather such terms can refer to any process or set of processes used to load and/or render an end-user experience of a web page and its resources in a browser or other application (i.e., “render” and “load” are used herein to generally express formulating the page using the resources). In one example, the web pages can include web browser pages; the page fetcher can include a web browser; and the resources can include uniform resource locators (URLs), hypertext markup language (HTML) objects, scripts, cookies, and/or other server-side objects used (e.g., needed in some or all instances) by the web browser to render the web pages. In another example, the web pages can include screens of an app (e.g., or any other application); the page fetcher can include the app (e.g., the portion of the app that handles input/output interactions); and the resources can be audio-visual content of the rendered screens.

Embodiments operate on “resources” and samples of resources. As used herein, the term “resource” refers generally to any of a data element (e.g., a file, script, etc.), a

collection of data elements (e.g., a web page, etc.), or an identifier of a data element or collection of data elements (e.g., a uniform resource locator (URL), script call, etc.). In some instances, resources can be embedded in other resources and/or can include collections of other resources. Embodiments of “resource samples” generally indicate a respective resource (e.g., by referring to the resource’s identifier) along with resource status information, but do not generally include the underlying data element or elements themselves.

Embodiments are described in context of “hints,” “hinting information,” and the like. As used herein, hints generally include any information about the resources used to render a web page that are provided to a page fetcher (or any suitable component of a client machine or a proxy system of the client machine) to help improve the page load timing for that web page by that page fetcher. This information may include a list of all resources requested as part of the transaction, a list of resources needed to present an initial incomplete web page on an output of a client device, a set of cookies (and/or hashed versions of those cookies) associated with the client device or processing operating on the client device, a set of cookies (and/or hashed versions of those cookies) associated with one or more web page resources or client processes, a set of timings associated with each resource, a set of timings associated with the overall page rendering process, a set of relationships between the resources, details associated with cached resources, resource sizes, resource types, resource fingerprints or checksums, resource position on the page, cookie meta-data, redirect chains, alternative content sources used during a transaction such as content delivery networks (CDNs) that may be used for some resources, details of the domains (including number of objects that are expected to be fetched per domain) used during the transaction, secure connection meta-data, secure socket layer (SSL) server certificate and/or revocation list information, and/or any other such details.

In various embodiments, after a page fetcher has completed rendering a web page and/or presenting the web page to a user, it can provide hinting feedback information that can include and/or be used to derive any hinting information for subsequent web page transactions (e.g., including any of the hinting information described above). The feedback information can be captured in any suitable manner, including by a client machine, by a page fetcher operating on a client device, by a web server, by a proxy server in a communication path between a client device and a web server, by an automated page fetcher under control of the a hinting service, or by any other device involved with a web page transaction. The hints can be used to improve web page loading times in web page transactions. For example, the improvement can be realized by lowering an overall time from a user selection via the page fetcher to a completed presentation of a web page to a user in response to that selection. This improvement can also be realized by lowering an initial time to presentation of an incomplete version of the web page that may be functional for user purposes. In one potential embodiment, a lowering of the overall time may result from the use of latency information in conjunction with other feedback information to determine how aggressively a page fetcher will attempt to prefetch child resources as part of future instances of the web page transaction.

Examples of hints and feedback information may be found in U.S. patent application Ser. No. 14/729,949, titled “SERVER BASED EMBEDDED WEB PAGE FEEDBACK AND PERFORMANCE IMPROVEMENT”; U.S.

patent application Ser. No. 13/372,347, titled “BROWSER BASED FEEDBACK FOR OPTIMIZED WEB BROWSING”; U.S. Pat. No. 9,037,638, titled “ASSISTED BROWSING USING HINTING FUNCTIONALITY”; U.S. patent application Ser. No. 14/212,538, titled “FASTER WEB BROWSING USING HTTP OVER AN AGGREGATED TCP TRANSPORT”; U.S. patent application Ser. No. 14/276,936, titled “CACHE HINTING SYSTEMS”; and U.S. patent application Ser. No. 14/729,949, titled “SERVER-MACHINE-DRIVEN HINT GENERATION FOR IMPROVED WEB PAGE LOADING USING CLIENT-MACHINE-DRIVEN FEEDBACK”; each of which is expressly incorporated by reference for all purposes in this application.

Resources used in such a web page may include HTML files, cascading style sheet (CSS) files, image files, video files, or any other such files. Reference to different instances of a web page transaction refers to the transaction being performed by different client machines at different times, or the same transaction being performed by a single client machine at different times. These different instances of a web page transaction may include variations in the resources that are part of the web page transaction, either due to customization across different client machines, or updates to the web page over time. Further, different web pages and different web page transactions may include resources that are the same or similar. In certain embodiments, feedback information and hints generated for a resource seen in one web page transaction may be applied as hints in a transaction for a separate web page if the root URLs are similar or if there is a sufficient degree of commonality between the sets of resources is used in both web page transactions. Similarly, as used herein, terms, like “render” and “load” are used broadly (and, in most cases, interchangeably) to refer generally to enabling interaction by a user with a page resource via a page fetcher interface. For example, rendering or loading can include displaying and/or formatting in context of static visual content, playing in context of video or audio content, executing in context of code or other scripts, etc.

Further, as used herein, “root” refers to an initial portion of a web page transaction that is initiated directly by a user selection or action or is predicted to be initiated by user action. For example, a user clicking on a web page link initiates a root request for that link. The root response is the response directly responding to that root request. The root response also includes a root resource. This root resource includes information that enables a page fetcher to identify, either directly or indirectly, the other resources needed to render and present the complete web page. In some instances, the “root” resource can include a primary child resource (e.g., a sub-resource) in an iframe on a page, or the like (e.g., where each of multiple iframes are separately hinted from different content servers).

“Redirect” refers to a response to a root request that directs the requesting client device to a single resource that has at least one sub-resource. For example, a client device may send a root request and receive back a redirect response. The client device may then send a redirected child request to the redirect target indicated in the redirect response. In certain embodiments, a response to the redirected child request may then include a feedback script or hints. Thus, while certain embodiments describe operation with a root request and response, in various embodiments, any root, child, or redirected response described herein may include a feedback script as described in the various embodiments herein.

“Child” requests and responses are the follow-on requests and responses that result, either directly or indirectly, from embedded or calculated references to other resources in root resources or other child resources. The child resources, requests, and responses are always one or more steps removed from the user action by a root that directly responds to the user action. Child resources may include references to additional child resources, resulting in a chain of requests and responses. Each of the above requests and responses may be hypertext transport protocol (HTTP) requests and responses including HTTP headers and an associated message. In various embodiments, other communication protocols may be used.

FIG. 1 shows an illustrative communications system environment **100** that provides a context for various embodiments. The communications system environment **100** includes client machine(s) **110**, content server(s) **120** (e.g., web servers), and hinting machine(s) **130** in communication over a communications network **140**. Network **140** can include any one or more suitable communications networks and/or communications links, including any wide area network (WAN), local area network (LAN), private network, public network (e.g., the Internet), wired network, wireless network, etc. Typically, the communications system environment **100** can include many client machines **110** interfacing with multiple content servers **120** over the communications network **140**.

As described herein, according to various embodiments, the content servers **120** can be in communication with one or more hinting machines **130** directly and/or via the communications network **140**, and/or the client machines **110** can be in communication with the hinting machines **130** directly and/or via the communications network **140** (e.g., at the direction of the content servers). Some embodiments are directed to improving the loading and rendering of resources that make up web pages, screens of applications, and/or other similar web page contexts. In such a context, it may be typical for a client machine **110** to make a request for a web page that is provided (e.g., hosted) by a content server **120**. Loading and rendering the requested web page can involve subsequently requesting and receiving a number (sometimes a large number) of resources that make up the web page (e.g., visual content, audio content, executable scripts, etc.). Loading and rendering of such a web page can be improved by requesting resources at particular times (e.g., by prefetching resources in a particular order, etc.), and the client machine can be instructed as to such improvements using “hints,” as described herein. The resources may be identified in the set of hints by URL, by a combination of URL and regular expression, by a script, or by other similar techniques. Loading and rendering of such a web page can also be improved by hints that support pre-resolving domain names, pre-establishing TCP connections, pre-establishing secure connections, predetermining and minimizing the redirect chain and similar functions that can be performed prior to content load that improve overall page load performance. Additionally, the probability that a resource will be needed and the priority it should be given by the browser may be communicated to further improve page load time. Additionally, the various image, video, and document formats that may be associated with a given resource may be sent to the device in advance as hints, thereby allowing the renderer to dynamically adjust to network conditions and constraints and minimize data traffic associated with pre-fetched resources. Additionally, hints may guide the selection of CDNs, caches, or other server locations so as to improve page load time.

Client machine(s) **110** can be implemented as any suitable computing device having memory resources, processing resources, and network communication resources. For example, the client machines **110** can be desktop computers, tablet computers, laptop computers, mobile phones, personal data assistants, network enabled wearable devices, network enabled home appliances, etc. Each client machine **110** includes one or more page fetchers **115**. Page fetcher **115** can include any system implemented in a client machine **110** that enables a web page transaction, and that is used, at least in part, for rendering a web page and presenting it to a user via an output device of the client machine **110**.

Content server(s) **120** can generally include any one or more computational environments for serving (e.g., hosting and/or otherwise providing access to) web page content to the client machines **110** via the communications network **140**. For example, the content servers **120** can include web servers, content distribution networks (CDNs), caches, or the like. As illustrated, the content servers **120** can include, or be in communication with, one or more data storage systems having web pages **125** stored thereon. As described herein, it is assumed that the web pages **125** are made up of multiple resources **127**. For example, loading one of the web pages **125** can involve requesting, receiving, and rendering the resources **127** that make up the web page **125**. Some or all of the resources **127** of the web pages **125** served by the content servers **120** can be stored in the data storage systems, or some or all of the resources **127** can be stored remote from the content servers **120**.

The one or more hinting machines **130** can be implemented as one or more stand-alone server computers, as part of one or more content servers **120**, and/or in any other suitable manner for maintaining and updating hinting information **135** (e.g., according to hinting feedback **147** from client machines **110**, according to hints **150** computed from the hinting information **135**, etc.). The hinting information **135** can be stored in one or more data stores that are part of, coupled with, or in communication with the hinting machines **130**, or in any other suitable manner. Embodiments support many different types of hinting information **135** and hints **150** generated therefrom, including, for example, information relating to which page objects **127** are needed to render the web pages **125**, timing information relating to those page objects **127** (e.g., the order and timing by which the page objects **127** should be requested), etc. The hinting information **135** can be maintained, computed, updated, etc. in any suitable manner, including according to the hinting feedback **147** received from one or more client machines **110**. Embodiments of the hinting machine **130** apply machine learning techniques to hinting feedback **147** from multiple related web page transactions (e.g., from multiple instances of multiple client machines **110** rendering the same (or sufficiently similar) web pages). Received hinting feedback **147** can be used to refine, hone, update, reinforce, or otherwise improve machine-driven hinting models maintained by the hinting machine **130**, thereby facilitating generation and communication of optimized hints.

The client machines **110** can render requested web pages **125** according to hints **150** generated from the hinting information **135** that effectively predict which resources **127** the client machines **110** will need at which times to optimally render the web pages **125**; the client machines **110** can actually render the web pages **125** according to at least to the received hints **150**; the actual rendering of the web pages **125** can be monitored by the client machines **110** to determine which resources **127** were actually used to render the

pages according to which timings; and the monitored information can be fed back (i.e., as the hinting feedback **147**) to the hinting machines **130** for use in updating the hinting information **135** and refining future hint **150** generation. The hints **150** can be generated for, and/or applied to rendering of, a particular web page **125** from which the hints were derived, other web pages **125** from the same or a similar domain, web pages **125** differing by only a portion of their path (or by dynamically generated fields, etc.), etc. For example, hinting information **135** (e.g., from time-based samples) gathered from a particular web page **125** may suggest time-dependency trends and/or other information with respect to all web pages in a particular domain (e.g., “breakingnews.com” pages have a banner at the top of the page that is the same across all pages in the domain and rarely changes, and they have a main story image that is in the same location with different content on every page in the domain, or the like).

Some embodiments generate and handle hints in a manner that is computationally generated (e.g., generated by machine based on feedback and analysis, as opposed to being generated manually by coders based on assumptions). As described herein, such machine-generated hinting can be enhanced by adding time dependency to the hinting. Embodiments of the hinting machines **130** can develop information about whether and how resources are used in network transactions (e.g., to render web pages) over time by collecting resource samples. The samples can be collected as part of receiving hinting requests (e.g., as part of page requests **141**) from client machines, as part of receiving hinting feedback **147** from client machines, as information monitored and/or generated during automated crawling of web pages (e.g., by the hinting machine **130** itself), and/or in any other suitable manner. The time-based samples can be used to compute time-based probabilities for the resources, which can be used to generate time-dependent hints.

FIG. 2A shows a block diagram of a portion of an illustrative communications environment **200** for implementing time-dependent hint generation, according to various embodiments. FIG. 2 shows a client machine **110** in communication with a hinting machine **130** over a network **140**, which can be an implementation of the system described above with reference to FIG. 1. Some of the descriptions involve communications between components of the client machine **110** and components of the hinting machine **130**, however these are intended only as a general illustrations of functionality and connectivity. As described with reference to FIG. 1, and as generally shown in FIG. 2, the hinting machine **130** can be in direct communication (over the network **140**) with the client machine **110**, in communication with the client machine **110** only via one or more content servers **120** (e.g., where the hinting machine **130** is in communication with the content servers **120** over one or more networks **140** and/or is part of one or more of the content servers **120**), in communication with one or more content servers **120** and the client machine **110** over one or more networks **140**, etc. For example, hinting functionality can be handled between the client machine **110** and the hinting machine **130** either without involving any content servers **120**, only by going through one or more content servers **120**, or in any suitable combination.

As illustrated, the client machine **110** can include a page fetcher **115**, such as a web browser. Embodiments of the page fetcher **115** can include a rendering engine **210**, a resource engine **220**, and a client hinting subsystem **230**. The rendering engine **210** can render resources of a web page for consumption (e.g., display, etc.) via a graphical user inter-

face (GUI) 215 of the client machine 110. For example, the rendering engine 210 can process HTML code, scripts, page objects, etc. to effectively provide a user experience of web pages via the GUI 215.

When a web page is requested, the resource engine 220 can generate requests for resources of the requested web page, communicate those requests to one or more content servers 120 over the network 140, receive the resources in response to the requests, and process the responses. For the sake of illustration, a user can request a web page via the GUI 215 (e.g., by entering a web address), the resource engine 220 can obtain some or all of the resources needed to render the requested web page (e.g., according to HTML code, scripts, cookies, page objects, etc.), and the rendering engine 210 can process the obtained resources to effectively provide a user experience of the requested web page via the GUI 215 (by rendering the web page using the resources).

Embodiments of the page fetcher 115 can exploit hints, as described herein, using the client hinting subsystem 230. Hinting functionality can be exploited at any or all of a number of stages in a web transaction. One stage is a web page request stage, during which various resource requests can be made to one or more content servers 120 (e.g., by the resource engine 220), and requests comparable to those resource requests can be made to the client hinting subsystem 230 for hints relating to those resources (e.g., by the client hinting subsystem 230). For example, in response to a user requesting a web page (or in response to predicting that a user will request a web page), the resource engine 220 can begin requesting resources (e.g., the resources pertaining to the root URL and child URLs), and the client hinting subsystem 230 can issue one or more requests indicating those resources' URLs to the hinting machine 130 seeking relevant hints. Another stage is a feedback stage. While the resources for a web page are being loaded, while the page is being rendered, etc., the client hinting subsystem 230 can collect feedback information, as described above (e.g., information on which resources are involved in rendering the web page, timing information relating to the resources, etc.). After the web page has been rendered by the rendering engine 210 (or during rendering, after presentation to the user via the GUI 215, after multiple pages have been rendered and feedback has been aggregated, or at any other suitable time), the client hinting subsystem 230 can send the hinting feedback to the hinting machine 130 for use in generating future hints for the web page and/or for the resources (e.g., for any web pages that invoke those resources).

Machine-generation of hints by the hinting machine 130 can generally involve aggregating and maintaining information about how and when resources are used to render web pages. For example, a hinting service can use so-called "waterfall data" from multiple past visits to a web page to compute a probability that a given resource (e.g., a child URL of the web page) will be used in a future visit. One technique for computing such a probability is to divide a number of occurrences of a given resource by a number of visits to the web page on which the resource is used, effectively yielding a likelihood that the resource will subsequently be used to render the web page. The probability can be refined by more strongly weighting presence or absence of a resource in more recent visits, for example, under the assumption that more recently sampled pages are less likely to have changed (e.g., even assuming that web pages change over time, it can generally be assumed that those changes are less likely to have occurred when less time has elapsed). However, such probabilities do not record, or

account for, actual time-dependencies of the resources on a page. For example, some resources can change much more or less frequently than others, and such changes can exhibit certain periodicity or other temporal characteristics, can indicate temporal characteristics of other related resources, etc. Embodiments described herein accumulate time-based information about resource rendering from which to develop and exploit time-based hinting probabilities and time-dependent hints. Such time-dependent hinting can provide a number of features, as described herein.

Embodiments of the hinting machine 130 include a server hinting subsystem 270, which can include a resource sampler 240 and a time-dependent hint (TDH) generator 260. The resource sampler 240 can receive resource samples and can store the resource samples in a sample data store 280. In some embodiments, the resource sampler 240 can receive resource samples by monitoring web transactions involving client machines 110 (e.g., and/or involving machines, such as proxies, acting on behalf of client machines 110). For example, when a client machine 110 issues a hinting request, provides hinting feedback, visits a web page, etc., the resource sampler 240 can monitor which resources were used to render the web page and timing information relating to loading those resources. In other embodiments, the server machine 130 (e.g., the resource sampler 240) can perform automated resource sampling. For example, the resource sampler 240 can include, and/or direct operation of, one or more "bots," or the like, that can autonomously crawl web pages and collect resource samples. Such automated approaches can include any suitable functionality for collecting resource samples, such as full browser instances, partial browser instances, etc. In some implementations, the automated browser approaches can model functionality of multiple types of browsers and/or multiple types of rendering platforms (e.g., for different operating systems, mobile versus desktop environments, etc.).

Each resource sample is recorded at a corresponding sample time and indicates a rendering status of the resource with respect to rendering a web page at the corresponding sample time (and the resource sample may be received at the sample time or at some subsequent time). The rendering status can include any information relating to the rendering of the resource in one or more web transaction contexts (e.g., on one or more web pages). For example, when a user visits a news-related web page at a first time, multiple resources can be loaded, including text, images, videos, scripts, etc. Some of the resources relate to relatively static content of the web page (e.g., data elements giving rise to the overall look and feel of the page), and other resources are relatively dynamic content of the web page (e.g., data elements relating to a particular news story, advertising banners, etc.). Accordingly, when the user visits the same page at a second time, some of the resources (e.g., the more dynamic resources on the page) may have changed since the first time. Thus, the rendering status can indicate which resources were loaded at which sample times.

Some embodiments of the resource sampler 240 can collect additional rendering status information about the resources as part of sample collection. Some implementations associate each sampled resource with one or more super-resources and/or sub-resources. For example, a group of resources can be child URLs of a particular logical context (e.g., web page, resource domain, root domain, etc.), and implementations can store those resources in association with their logical context; or a particular resource can be a script or page that calls one or more child resources, and implementations can store the resource with such an indi-

cation. Other implementations can store information in association with resource samples, such as file type, one or more resource indicators (e.g., a URL, one or more URLs identified as pointing to an equivalent resource, etc.), resource rendering properties (e.g., size relative to a web page, location on the web page, interactivity with user devices and/or other resources on the web page, etc.). For example, a web page can be laid out in such a way that the top ten percent of the page has content that never changes, the left ten percent of the page has content that changes on the first day of each month, and the remainder of the page has highly dynamic content.

The TDH generator **260** can calculate, as a function of the stored resource samples, a time-based probability of each resource being fetched over time as part of rendering the web page. As resource samples are collected over time, some or all of the samples (e.g., rendering status of resources at sample times) can be added to statistical models. The statistical model effectively computes a probability that a particular resource will be rendered in association with a particular web transaction at a particular time (or times) in the future as a function of whether (e.g., and how, when, etc.) the resource was rendered in association with other web transactions at previous sample times. FIGS. **3** and **4A-4D** show some examples of time-based resource probability information for use with various embodiments.

FIG. **3** shows an example graph **300** of a time-based probability function **350** (i.e., probability **320** versus time **310**) for an illustrative resource. It is assumed that a number of samples were collected over a previous timeframe and were stored as “past data” **325**. Based on the past data **325**, the time-based probability function **350** can be computed and plotted. For example, the past data **325** can be used to compute a statistical trend curve. As illustrated, the past data **325** can include some or all samples of a particular resource (e.g., and, in some cases, certain related resources) up to a “last sample time” **330 k**, which can be the most recent time at which a sample was collected relating to the resource of interest.

The “time” **310** associated with samples and/or with computing the time-based probability function **350** can be expressed in any suitable manner. In some embodiments, the time **310** can be expressed as a relative time with reference to the request time **340**. For example, past data **325** can be expressed as an amount of time in the past relative to the request time **340** and/or future predicted probabilities can be expressed with reference to amounts of time from “t=0,” or the like, where “t=0” is the request time. In other embodiments, the time **310** can be expressed with reference to an absolute time scale, such as a timestamp (e.g., date and time, rounded to the nearest second, or the like). The absolute time can be based on a location (e.g., time zone) of the hinting machine **130**, a pre-negotiated time basis (e.g., Greenwich mean time, time measured from a defined epoch, etc.), etc.

In some implementations, one or more additional mathematical considerations can be included in computing the time-based probability function **350**. As one example, some implementations can apply a decay function to the time-based probability function **350**, so that the predicted future probability decreases in a particular manner (e.g., by a predetermined slope, decay rate, half-life, etc.) over time. In certain such implementations, the decay function can be applied to an instantaneous probability and/or any time of time-based probability computation (e.g., after a last data sample is collected, the probability for that resource can monotonically decrease according to the hint decay function). In some instances, application of the decay function

does not require that the overall probability function is monotonically decreasing; rather the hint decay function can produce a contribution that effectively decreases the time-based probability function **350** over time. One example of a hint decay function is a square function that starts at one (e.g., 100%) and drops to zero (e.g., 0%) at a certain time, thereby representing an expiration time for a particular hint, or the like. As another example of additional mathematical considerations that can be included in computing the time-based probability function **350**, some implementations can apply a weighting function to resource samples in the past data **325** to favor some samples over others. The weighting can be based on “freshness” (e.g., more recent samples can be weighted more favorably than older samples), on domain relationships (e.g., samples of the resource recorded in association with a requested domain can be weighted more heavily than samples recorded for the same resource in association with other domains), on platform relationships (e.g., samples of the resource recorded in association with platforms similar to a presently requesting platform can be weighted more heavily than samples recorded for other platforms), etc.

The time-based probability function **350** can be computed in any suitable manner and at any suitable time. For example, the time-based probability function **350** can be re-computed each time a new sample is collected for a resource, periodically, in response to a hinting request, etc. As described herein, the computed time-based probabilities can be used ultimately to develop time-dependent hints. Accordingly, in some instances, there is a “request time” **340** at which a particular domain, resource, etc. is requested, and the time-based probability function **350** is exploited. It can generally be assumed that the request time **340** follows the last sample time **330 k**, so that the time-based probability function **350** is useful for predicting a time-dependent rendering probability of a particular resource substantially at the request time **340** (i.e., an instantaneous probability) and/or at one or more future times (e.g., one or more instantaneous probabilities associated with particular future times, one or more average probabilities associated with one or more future timeframes, one or more probability functions associated with one or more future timeframes, etc.).

In some instances, rendering status of resources can be modeled according to one or more presence models. Each presence model can effectively be a score, a parametric function, a machine learning model, a statistical model, etc. Some embodiments can attempt to statistically fit resource rendering status data into one or more predetermined presence models. FIGS. **4A-4D** show graphical plots **400** of sets of resource samples that can be fit into illustrative types of presence models. Each plot **400** shows samples of resource presence **420** for a particular resource at multiple sample times **330** (e.g., from some sample time **330 a** to some last sample time **330 k**). For the sake of simplicity, each presence **420** is plotted in a binary fashion (e.g., as “present” or “not present”), and a line is drawn through the sample points. The plots **400** are not intended to limit the types of data, amounts of data, etc. that can be collected, or the manner in which it can be expressed. For example, the sample times **330** may not be equally spaced, there may be more than two dimensions (e.g., the presence may account for other information, such as location, platform, etc., as described above), etc.

Turning to a first example, FIG. **4A** shows resource samples following a “short-term regular presence” type of presence model. For example, the most recent N samples for this resource indicates presence, but some prior samples indicate absence. This can suggest that the resource is

consistently rendered as part of a particular web page, but the consistency is only evident in the short term. Some implementations can compute a time-based probability function 350 from such data to reflect a high probability of this resource being rendered with this web page, though the computed function can also indicate a lower probability and/or a sharper decay in accordance with the short-term nature of the consistency. For example, as the data remains consistent for a longer amount of time, the computed time-based probability function 350 may indicate a higher probability and/or less decay over time. Further, the presence model can be implemented to consider occasional indications of absence in various manners. For example, one implementation can consider a resource as no longer “regular” when there is a single sample of absence. Another implementation can consider a resource as “regular” whenever there is a minimum threshold number of consecutive samples of presence. Another implementation can consider a resource as “regular” whenever there is fewer than a maximum threshold number (or frequency) of consecutive samples of absence.

Turning to a second example, FIG. 4B shows resource samples following a “discarded” type of presence model. For example, the most recent N samples for this resource indicates absence, while prior samples indicate presence. This can suggest that the resource was previously rendered as part of a particular web page, but is apparently no longer part of the web page. Some implementations can compute a time-based probability function 350 from such data to reflect a low (or zero) probability of this resource being rendered with this web page. In certain implementations, the low probability can be further impacted (e.g., weighted) by the persistence (e.g., number of samples, freshness of the samples, etc.) of the absence indications. For example, as the absence data remains consistent for a longer amount of time, the computed time-based probability function 350 may indicate a lower probability.

Turning to a third example, FIG. 4C shows resource samples following a “one-off” type of presence model. For example, the sample data shows a single (or limited number of) samples indicating presence amid a large number of samples (before and after) indicating absence. This can suggest that the resource was rendered once (or a limited number of times) as part of a particular web page, but is apparently not presently part of the web page. Some implementations can compute a time-based probability function 350 from such data to reflect a low (or zero) probability of this resource being rendered with this web page. In certain implementations, the low probability can be further impacted (e.g., weighted) by the persistence (e.g., number of samples, freshness of the samples, etc.) of subsequent presence and/or absence indications.

Turning to a fourth example, FIG. 4D shows resource samples following a “transitory” or “periodic” type of presence model. For example, the sample data shows a pattern of presence and absence over time. This can suggest that the resource tends to be rendered as part of a particular web page during certain times (e.g., certain times of day, month, year, etc.) and not otherwise, but in a manner that is deterministic to a level of statistical confidence. Some implementations can compute a time-based probability function 350 from such data to reflect a probability that substantially follows the deterministic pattern. For example, the computed time-based probability function 350 can follow a periodic function (e.g., a step or sinusoidal function, etc.), or the like. For the sake of illustration, such periodic probabilities can be present in a web page that is updated

with new content at some deterministic period (e.g., every Wednesday morning at 5:00 am).

The examples provided in FIGS. 3-4D are intended only to illustrate certain types of persistence models and time-based probability functions 350, and are not intended to include all types or to limit implementations to any numbers or types of models or functions. Further, embodiments can tune the models and or time-based probability function 350 computations in any suitable manner. As one example, time-based probability functions 350 can be computed from the resource samples using a sliding window that defines a timeframe of relevance, and the size of the window can be adjusted based on certain factors, different for different types of models, etc. As another example, machine learning and/or similar techniques can be used to develop persistence models that may or may not follow regular patterns. For example, principle component analyses, or other types of data analysis, can be used to extract the persistence features having the most relevance and the manners in which they are relevant; and those extracted features can be used to formulate persistence models (e.g., dynamically, periodically, etc.).

Returning to FIG. 2A, embodiments of the TDH generator 260 can use the calculated time-based probabilities to generate time-dependent hints for prefetching the set of resources in association with rendering the web page by a client machine. For example, having computed predictions of presence probabilities for resources over time, those predictions can be exploited in determining which resources to prefetch (e.g., and/or in which priorities, orders, etc.) in response to a request for loading a web page. The time-dependent hints for a particular resource can be generated as a function of the respective time-based probability function(s) 350 (e.g., which may be expressed as a set of data points, a mathematical expression, and/or in any other suitable manner) associated with that resource and the request time. In some embodiments, the time-dependent nature of the hints can increase the likelihood that the most relevant resources will be fetched in the most optimal order, thereby improving page load times and/or otherwise improving performance of web transactions. In other embodiments, availability of predicted time-based probabilities (e.g., functions, data points, etc.) can be exploited to generate time-dependent hints even when further information is not available at the request time, for example, when hinting information is otherwise outdated, a client machine 110 is unable to access the hinting machine 130, etc.

Embodiments of the hinting machine 130 can include a communications subsystem 250 that can communicate the generated time-dependent hints to one or more client machines 110. In some embodiments, the communications subsystem 250 can also receive and handle hinting requests and/or other hinting related communications with client machines 110, content servers 120, etc. For example, the communications subsystem 250 can receive a hinting request from a client machine 110 over the communications network 140 at a request time in association with the client machine 110 rendering a web page. The TDH generator 260 can generate, in response to the hinting request, a hinting response that includes time-dependent hints generated from respective time-based probabilities (e.g., computed before and/or at the request time). The communications subsystem 250 can then communicate the hinting response to the client machine 110 in response to the hinting request.

In some embodiments, the TDH generator 260 can generate the time-dependent hints by calculating instantaneous hinting probabilities for one or more of the time-dependent

hints as a function of the request time and of the respective time-based probability for the resources associated with those one or more time-dependent hints. For example, the instantaneous probability can be the computed probability at the request time as a function of a time-based probability function associated with the resource. The communications subsystem **250** can then communicate the hinting response by communicating the time-dependent hint along with its associated instantaneous probability.

In other embodiments, the TDH generator **260** can generate the time-dependent hints by calculating one or more hinting probability functions as a function of the respective time-based probabilities for one or more resources associated with one or more time-dependent hints. As described above (e.g., with reference to FIGS. 3-4D), the hinting probability functions can indicate probabilities of the resource being requested as part of rendering the web page by the requesting client machine at times subsequent to the request time. The communications subsystem **250** can then communicate the hinting response by communicating the time-dependent hint along with the one or more hinting probability functions. As illustrated, in some embodiments, further hinting information can be stored in the same or another hinting information store **135**. The additional hinting information can include any information useful for performing static, time-dependent, and/or other hinting functionality.

For added clarity, FIG. 5 shows an illustrative system **500** for implementing a data flow, according to various embodiments. The system can include means for receiving a plurality of resource samples **515**. As described herein, the means can include any suitable hardware (e.g., and supporting software) for communicating over a network and/or loading resources in performance of (or simulation of, etc.) a web transaction, such as antennas, physical and/or logical ports, protocols, modems, routers, etc. As illustrated, the means can include a resource sampler **240** and a resource sample store **280**. The resource sampler **240** can collect samples **515** of resources in association with bot-driven requests **503** and/or client-driven requests **505** for web transactions (e.g., for loading of web pages). The collected samples **515** can be stored in a resource sample store **280** in any suitable manner. For example, the samples **515** can be grouped by associated resource **510**, etc. The sample data store **280** can include any suitable tangible storage hardware and supporting hardware and/or software.

Some embodiments of the resource sampler **240** can also include a resource profiling engine **520** for generating, fitting, and/or otherwise determining and exploiting resource relationships **525**. For example, as described above, the resource relationships can include locations of resources on pages, groups of resources associated with a same page, resources of a particular file type, etc. In some embodiments, the time-based probabilities and/or time-dependent hints for a particular resource can be determined as a function of the time-based probabilities and/or time-dependent hints for one or more other related resources. Some embodiments of the resource profiling engine **520** can also generate and/or fit presence models and/or other types of profiles.

The system **500** further includes means for calculating, as a function of the resource samples **510**, a time-based probability **535** of each resource **510** being fetched over time as part of rendering the web page. For example, the resource samples **515** and/or the resource relationships **525** can be provided to the means for calculating, which can include a TDH generator **260** for generation of time-dependent hints **550**. For example, the means for calculating can be imple-

mented as a time-based probability engine **530** that is part of the TDH generator **260**. The time-based probability engine **530** can include hardware, such as hardware computational platforms and associated software, for receiving the resource samples **515** and/or the resource relationships **525** and calculating time-based probabilities **535** for the sampled resources **510**, accordingly. The TDH generator **260** can further include means for generating, according to the respective time-based probabilities **535**, time-dependent hints **550** for prefetching the set of resources **510** in association with rendering the web page by a client machine (e.g., client machines **110**). For example, the means for generating the time-dependent hints **550** can include computational hardware and associated software for receiving the computed time-based probabilities **535** (e.g., and additional hinting information **135**), and formulating the time-dependent hints **550** according to one or more data formats, protocols, etc.

In some implementations, the client machines **110** can store the received time-based probabilities for use in client machine-driven hint generation. For example, in instances where the client machine **110** determines that it is preferable to self-generate hints (e.g., where it is determined that there is no connection with a hinting machine **130**, where the connection with the hinting machine **130** is determined to be slow or unreliable, etc.), the client machine **110** can use the stored time-based probability function to generate its own hints for the associated resource in a manner that accounts for time dependence in context of the request time. Embodiments of the client machines **110** can receive the time-dependent hints from the hinting machine(s) **130** over the communications network **140**. The client hinting subsystem **230** (e.g., which can include a page fetcher and/or any other suitable components) can prefetch at least some of the resources in association with loading the web page and in accordance with the received time-dependent hints. In some implementations, the client hinting subsystem **230** includes a hint store that can store the received time-dependent hints with their associated hinting probabilities (e.g., associated time-based probability functions) as calculated by the hinting machine(s) **130**. In such implementations, the client hinting subsystem **130** (e.g., the page fetcher) can prefetch some or all of the resources by computing a set of client-side hints for those associated resources as a function of the request time and the stored hinting probability functions, and prefetching the associated resources according to the set of client-side hints.

FIG. 2B shows a block diagram of a portion of another illustrative communications environment **200 b** for implementing time-dependent hint generation, according to various embodiments. Embodiments of the communications environment **200 a** can be implemented in a manner that is substantially similar or identical to that of the communications environment **200 a** described with reference to FIG. 2A, except that the server machine **130** is implemented as part of the client machine **110** in FIG. 2B. Accordingly, similar components are identified by the same reference designators in FIGS. 2A and 2B for added clarity. Such designation is intended to indicate similarity of function and not to limit possible implementations for those components.

For example, the resource sampler **240** and the TDH generator **260** can be implemented as part of a hinting processor **270**. The hinting processor can include any hardware and/or software for implementing time-dependent hinting, as described with respect to the resource sampler **240** and the TDH generator **260**. Embodiments of client machines **110** having integrated hinting machines **130** can be

used to provide various features. One such feature is provision of peer-to-peer hinting services. For example, the hinting machines **130** integrated in client computers **110** can be used for peer-to-peer aggregation of hints across some or all peers, for distributed machine-driven hint generation, etc. Another such feature is generation of hints by a client based on its own hinting information. For example, the client machine **110** can maintain its own hinting feedback and/or collect hinting feedback from other client machines **110** (e.g., periodically by some synchronization process, using a dictionary or client model, etc.), and the client machine **110** can generate its own hints, as needed, without consulting any other client machines **110** or hinting machines **130**.

FIG. 6 shows a flow diagram of an illustrative method **600** for time-dependent machine-generation of hints, according to various embodiments. Embodiments of the method **600** can be implemented by any suitable system, such as the systems described with reference to FIGS. 1-3. The method **600** can begin at stage **604** by receiving resource samples (e.g., by a hinting machine). Each resource sample can be recorded at a corresponding sample time and can indicate a rendering status of the resource with respect to rendering a web page at the corresponding sample time. At stage **608**, embodiments can calculate, as a function of the resource samples, a time-based probability of each resource being fetched over time as part of rendering the web page. At stage **612**, embodiments can generate, according to the respective time-based probabilities, time-dependent hints for prefetching the set of resources in association with rendering the web page by a client machine.

FIG. 7 shows a flow diagram of another method **700** for time-dependent hinting, according to various embodiments. Embodiments of the method **700** can begin at stage **704** by receiving a hinting request (e.g., at a hinting machine from a client machine) at a request time in association with the client machine rendering the web page. At stage **708**, embodiments can generate, in response to the hinting request, a hinting response that includes time-dependent hints (e.g., at least some of the time-dependent hints generated in stage **616** of FIG. 6). At stage **612**, embodiments can communicate the hinting response (e.g., from the hinting machine) to the client machine in response to the request. According to some embodiments of the method **700**, the generating at stage **708** can include calculating an instantaneous hinting probability for one or more of the time-dependent hints as a function of the request time and of the respective time-based probability for resources associated with the one or more hints (illustrated as **708 a**). In such embodiments, the communicating at stage **712** can include communicating the time-dependent hint along with the instantaneous probability (illustrated as **712 a**). According to other embodiments, the generating at stage **708** can include calculating a hinting probability function as a function of the respective time-based probability for resources associated with one or more hint, such that the hinting probability function indicates probabilities of the resource being requested as part of rendering the web page by the requesting client machine at multiple times subsequent to the request time (illustrated as **708 b**). In such embodiments, the communicating at stage **712** can include communicating the time-dependent hint along with the hinting probability function (illustrated as **712 b**).

FIG. 8 provides a schematic illustration of one embodiment of a computer system **800** that can perform the methods of the invention, as described herein, and/or can function, for example, as any part of client machine(s) **110**, content server(s) **120**, hinting machine(s) **130**, or any other

such computer or device. It should be noted that FIG. 8 is meant only to provide a generalized illustration of various components, any or all of which may be utilized, as appropriate. FIG. 8 therefore broadly illustrates how individual system elements may be implemented in a relatively separated or relatively more integrated manner.

The computer system **800** is shown comprising hardware elements that can be electrically coupled via a bus **805** (or may otherwise be in communication, as appropriate). The hardware elements can include one or more processors **810**, including, without limitation, one or more general-purpose processors and/or one or more special-purpose processors (such as digital signal processing chips, graphics acceleration chips, and/or the like); one or more input devices **815**, which can include, without limitation, a mouse, a keyboard, touchscreen, and/or the like; and one or more output devices **820**, which can include, without limitation, a display device, a printer, and/or the like.

The computer system **800** may further include (and/or be in communication with) one or more storage devices **825**, which can comprise, without limitation, local and/or network accessible storage and/or can include, without limitation, a disk drive, a drive array, an optical storage device, a solid-state storage device such as a random access memory (“RAM”) and/or a read-only memory (“ROM”), which can be programmable, flash-updateable, and/or the like. The computer system **800** might also include a communications subsystem **830**, which can include, without limitation, a modem, a network card (wireless or wired), an infrared communication device, a wireless communication device, and/or chipset (such as an 802.11 device, a WiFi device, a WiMax device, cellular communication facilities, etc.), and/or the like. The communications subsystem **830** may permit data to be exchanged with a network (such as the network described below, to name one example), and/or any other devices described herein. In many embodiments, the computer system **800** will further comprise a working memory **835**, which can include a RAM or ROM device, as described above.

The computer system **800** also can comprise software elements, shown as being currently located within the working memory **835**, including an operating system **840** and/or other code, such as one or more applications **845**, which may comprise computer programs of the invention and/or may be designed to implement methods of the invention and/or configure systems of the invention, as described herein. Merely by way of example, one or more procedures described with respect to the method(s) discussed above might be implemented as code and/or instructions executable by a computer (and/or a processor within a computer). A set of these instructions and/or code might be stored on a computer-readable storage medium, such as the storage device(s) **825** described above. In some cases, the storage medium might be incorporated within a computer system, such as the system **800**. In other embodiments, the storage medium might be separate from a computer system (i.e., a removable medium, such as a compact disc, etc.), and/or provided in an installation package, such that the storage medium can be used to program a general-purpose computer with the instructions/code stored thereon. These instructions might take the form of executable code, which is executable by the computer system **800**, and/or might take the form of source and/or installable code which, upon compilation and/or installation on the computer system **800** (e.g., using any of a variety of generally available compilers, installation programs, compression/decompression utilities, etc.), then takes the form of executable code. In certain embodiments,

this may include page fetcher functionality and may include separate page fetcher modules as part of this page fetcher functionality executed by a process to enable display of a web page on an output device **820** of such a computer system **800**.

It will be apparent to those skilled in the art that substantial variations may be made in accordance with specific requirements. For example, customized hardware might also be used, and/or particular elements might be implemented in hardware, software (including portable software, such as applets, etc.), or both. Further, connection to other computing devices such as network input/output devices may be employed.

In one aspect, the invention employs a computer system (such as the computer system **800**) to perform methods of the invention. According to a set of embodiments, some or all of the procedures of such methods are performed by the computer system **800** in response to processor **810** executing one or more sequences of one or more instructions (which might be incorporated into the operating system **840** and/or other code, such as an application **845**) contained in the working memory **835**. Such instructions may be read into the working memory **835** from another machine-readable medium, such as one or more of the storage device(s) **825**. Merely by way of example, execution of the sequences of instructions contained in the working memory **835** might cause the processor(s) **810** to perform one or more procedures of the methods described herein.

The terms “machine-readable medium” and “computer-readable medium”, as used herein, refer to any medium that participates in providing data that causes a machine to operate in a specific fashion. In an embodiment implemented using the computer system **800**, various machine-readable media might be involved in providing instructions/code to processor(s) **810** for execution and/or might be used to store and/or carry such instructions/code (e.g., as signals). In many implementations, a computer-readable medium is a physical and/or tangible storage medium. Such a medium may take many forms including, but not limited to, non-volatile media. Non-volatile media includes, for example, optical or magnetic disks, such as the storage device(s) **825**. Common forms of physical and/or tangible computer-readable media include, for example, a flexible disk, hard disk, magnetic tape or any other magnetic medium, a CD-ROM or any other optical medium, solid-state circuit based memory or any other memory chip or cartridge, or any other medium from which a computer can read instructions and/or code. Various forms of machine-readable media may be involved in carrying one or more sequences of one or more instructions to the processor(s) **810** for execution. Merely by way of example, the instructions may initially be carried on a memory of a remote computer. A remote computer might load the instructions into its dynamic memory and send the instructions as signals over a transmission medium to be received and/or executed by the computer system **800**.

The communications subsystem **830** (and/or components thereof) generally will receive the signals, and the bus **805** might then carry the signals (and/or the data, instructions, etc., carried by the signals) to the working memory **835**, from which the processor(s) **810** retrieves and executes the instructions. The instructions received by the working memory **835** may optionally be stored on a storage device **825** either before or after execution by the processor(s) **810**.

A set of embodiments includes systems for implementing time-dependent hinting. FIG. **9** illustrates a schematic diagram of a network system **900** that can be used in accordance with one set of embodiments. In such embodiments,

the network system **900** may represent any number of client and server devices that enable content to be communicated from content providers to user systems as part of web page transactions across a network. The system **900** can include one or more user computers **905**, such as computers for implementing client machine(s) **110** of FIG. **1**. The user computers **905** can be general-purpose personal computers and/or can have any of a variety of applications, including one or more applications configured to perform methods of the invention, as well as one or more office applications, database client and/or server applications, and page fetcher applications. Alternatively, the user computers **905** can be any other electronic device, such as a thin-client machine, Internet-enabled mobile telephone, tablet computer, phablet, wearable device, Internet-enabled appliance, and/or personal digital assistant (PDA) capable of communicating via a network (e.g., the network **910** described below) and/or displaying and navigating web pages or other types of electronic documents. Although the exemplary system **900** is shown with three user computers **905 a-c**, any number of user computers can be supported.

Certain embodiments of the invention operate in a networked environment, which can include a network **910**, such as for implementing the network **140** of FIG. **1**. The network **910** can be any type of network familiar to those skilled in the art that can support data communications using any of a variety of commercially-available protocols, including, without limitation, TCP/IP, UDP/IP, SNA, IPX, and the like. Merely by way of example, the network **910** can be a local area network (“LAN”), including, without limitation, an Ethernet network, a Token-Ring network and/or the like; a wide-area network (WAN); a virtual network, including, without limitation, a virtual private network (“VPN”); the Internet; an intranet; an extranet; a public switched telephone network (“PSTN”); an infrared network; a wireless network, including, without limitation, a network operating under any of the IEEE 802.11 suite of protocols, or any other wireless protocol; and/or any combination of these and/or other networks.

Embodiments of the invention can include one or more servers **915** (or similar types of computational systems). Embodiments of the servers **915** can be used to implement the content server(s) **120** and/or the hinting machine(s) **130**. As described above, the hinting machine(s) **130** can also be part of one or more content servers **120** and/or part of one or more client machines **110**, which can be implemented as one or more of the servers **915**. Each of the servers **915** may be configured with an operating system, including, without limitation, any of those discussed above, as well as any commercially (or freely) available server operating systems. Each of the servers **915** may also be running one or more applications, which can be configured to provide services to one or more user computers **905** and/or other servers **915**.

Merely by way of example, one of the servers **915** may be a web server, which can be used, merely by way of example, to process requests for web pages or other electronic documents from user computers **905**. The web server can also run a variety of server applications, including HTTP servers, FTP servers, CGI servers, database servers, script servers, and the like. In some embodiments of the invention, the web server may be configured to serve web pages that can be operated within a page fetcher on one or more of the user computers **905** to perform methods of the invention. In certain embodiments, the servers **915** may also include CDN devices which provide similar or identical content from an alternate server than the primary content server which is a source for particular objects in a web page transaction.

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The servers **915**, in some embodiments, might include one or more application servers, which can include one or more applications accessible by a client running on one or more of the user computers **905** and/or other servers **915**. Merely by way of example, the server(s) **915** can be one or more general-purpose computers capable of executing programs or scripts in response to the user computers **905** and/or other servers **915**, including, without limitation, web applications (which might, in some cases, be configured to perform methods of the invention). Merely by way of example, a web application can be implemented as one or more scripts or programs written in any suitable programming language. The application server(s) can also include database servers which can process requests from clients (including, depending on the configurator, database clients, API clients, page fetchers, etc.) running on a user computer **905** and/or another server **915**. In some embodiments, an application server can create web pages dynamically for displaying the information in accordance with embodiments of the invention, such as information displayed as part of various page fetchers discussed herein. Data provided by an application server may be formatted as web pages (e.g., comprising HTML, scripts, etc.) and/or may be forwarded to a user computer **905** via a content server **120**. Similarly, a content server **120** can receive web page requests and/or input data from a user computer **905** and/or forward the web page requests and/or input data to an application server. In some cases, a content server **120** may be integrated with an application server.

In accordance with further embodiments, one or more servers **915** can function as a file server and/or can include one or more of the files (e.g., application code, data files, etc.) necessary to implement methods of the invention incorporated by an application running on a user computer **905** and/or another server **915**. Alternatively, as those skilled in the art will appreciate, a file server can include all necessary files, allowing such an application to be invoked remotely by a user computer **905** and/or server **915**. It should be noted that the functions described with respect to various servers herein (e.g., application server, database server, web server, file server, etc.) can be performed by a single server and/or a plurality of specialized servers, depending on implementation-specific needs and parameters.

In certain embodiments, the system can include one or more databases **920**, such as for implementing a resource sample data store **280**, a hinting information data store **135**, and/or any other suitable data store used by systems and methods of various embodiments. Such databases may include stores of web transaction history and hints derived from this web transaction history. Any supporting details related to creation of such hints may additionally be stored in such a database. The location of the database(s) **920** is discretionary: merely by way of example, a database **920 a** might reside on a storage medium local to (and/or resident in) a server **915 a** (and/or a user computer **905**). Alternatively, a database **920 b** can be remote from any or all of the computers **905** or servers **915 a, b**, so long as the database **920 b** can be in communication with one or more of these (e.g., via the network **910**). In a particular set of embodiments, a database **920** can reside in a storage-area network (“SAN”) familiar to those skilled in the art. Likewise, any necessary files for performing the functions attributed to the computers **905** or servers **915** can be stored locally on the respective computer and/or remotely, as appropriate. In one set of embodiments, the database **920** can be a relational database that is adapted to store, update, and retrieve data in response to SQL-formatted commands. The database might

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be controlled and/or maintained by a database server, as described above, for example.

In any embodiment described herein, any communication, hypertext transport protocol (HTTP) request or response, web page transaction, portion of a web page transaction, or any combination of any communications in whole or in part that may use HTTP may also be implemented using hypertext transport protocol secure (HTTPS). The use of HTTPS involves encryption and various security measures, and any embodiment described herein may be adapted to implement systems and methods described herein to accommodate the encryption and security associated with HTTPS in a number of ways.

In certain embodiments, proxy devices involved in any communication described herein may be provided with details associated with HTTPS communications in order to enable any proxy device functionality described herein. Such details may be provided by a user device with user consent to enable proxy device or hinting machine device interaction with the user’s communications. This may enable decryption of HTTPS communication by the proxy to enable any functionality described herein. Such details to enable decryption may also be provided by a content server or content server operator to enable proxy device interaction with the content provider’s communications. For aspects of embodiments described herein relating to client-side functionality or page fetcher functionality, certain embodiments may function with the same implementation described above for proxy devices. This functionality may be used as well with any other server side or content device.

In other embodiments, rather than a proxy decryption of HTTPS communications, a browser on a user device may interact with a proxy device or a hinting machine device, independent of the original HTTPS communication to provide details of the HTTPS communication to the proxy device or hinting machine device. In a user device page fetcher, this may involve the use of a page fetcher module, page fetcher plug-in, or page fetcher with specialized core functionality to observe HTTPS communications before they are encrypted. If needed, the independent communications with the proxy device or hinting machine device may then additionally be subject to security similar to the security used for the original HTTPS communication. For embodiments described herein which may involve integration with content provider systems or reverse proxy systems, HTTPS communication received at the content provider system or reverse proxy may be used as part of the embodiments described herein after the HTTPS communication is decrypted by the content provider system or reverse proxy. Thus, any “observing” or “identifying” functionality described herein may be performed with HTTPS communications for client machines, proxy devices, and content provider devices. Similarly, any embodiment described herein may be implemented with other secure connection and communication systems or protocols in addition to HTTPS described above.

Certain embodiments described herein refer to proxy devices or proxy systems. As described herein, proxy devices may be one or more devices operating as part of a system to intercept communications between user devices and content devices. Such proxies may be transparent to the user and content devices, or may be part of a multi-step communication path which is apparent to user and content devices. In certain embodiments, proxy devices may function as part of a forward proxy system, where communications from a group of user devices are all communicated to a broader network (such as the Internet) via the forward

proxy system. In alternate embodiments, the proxy devices may function as part of reverse proxy systems, where a reverse proxy system operates as an access path to a number of content server devices. It will be apparent that embodiments described herein as including a proxy will apply to both forward proxy systems and reverse proxy systems, and any configuration of a system including a proxy, given appropriate accommodations for the particular system structure.

The methods disclosed herein include one or more actions for achieving the described method. The method and/or actions can be interchanged with one another without departing from the scope of the claims. In other words, unless a specific order of actions is specified, the order and/or use of specific actions can be modified without departing from the scope of the claims.

The functions described can be implemented in hardware, software, firmware, or any combination thereof. If implemented in software, the functions can be stored as one or more instructions on a tangible computer-readable medium. A storage medium can be any available tangible medium that can be accessed by a computer. By way of example, and not limitation, such computer-readable media can include RAM, ROM, EEPROM, CD-ROM, or other optical disk storage, magnetic disk storage, or other magnetic storage devices, or any other tangible medium that can be used to carry or store desired program code in the form of instructions or data structures and that can be accessed by a computer. Disk and disc, as used herein, include compact disc (CD), laser disc, optical disc, digital versatile disc (DVD), floppy disk, and Blu-Ray® disc where disks usually reproduce data magnetically, while discs reproduce data optically with lasers.

A computer program product can perform certain operations presented herein. For example, such a computer program product can be a computer readable tangible medium having instructions tangibly stored (and/or encoded) thereon, the instructions being executable by one or more processors to perform the operations described herein. The computer program product can include packaging material. Software or instructions can also be transmitted over a transmission medium. For example, software can be transmitted from a website, server, or other remote source using a transmission medium such as a coaxial cable, fiber optic cable, twisted pair, digital subscriber line (DSL), or wireless technology such as infrared, radio, or microwave.

Further, modules and/or other appropriate means for performing the methods and techniques described herein can be downloaded and/or otherwise obtained by suitable terminals and/or coupled to servers, or the like, to facilitate the transfer of means for performing the methods described herein. Alternatively, various methods described herein can be provided via storage means (e.g., RAM, ROM, a physical storage medium such as a CD or floppy disk, etc.), such that a user terminal and/or base station can obtain the various methods upon coupling or providing the storage means to the device. Moreover, any other suitable technique for providing the methods and techniques described herein to a device can be utilized. Features implementing functions can also be physically located at various positions, including being distributed such that portions of functions are implemented at different physical locations.

In describing the present invention, the following terminology will be used: The singular forms “a,” “an,” and “the” include plural referents unless the context clearly dictates otherwise. Thus, for example, reference to an item includes reference to one or more items. The terms “one” or “ones”

refers to one, two, or more, and generally applies to the selection of some or all of a quantity. The term “plurality” refers to two or more of an item. The term “about” means quantities, dimensions, sizes, formulations, parameters, shapes and other characteristics need not be exact, but can be approximated and/or larger or smaller, as desired, reflecting acceptable tolerances, conversion factors, rounding off, measurement error and the like and other factors known to those of skill in the art. The term “substantially” means that the recited characteristic, parameter, or value need not be achieved exactly, but that deviations or variations including, for example, tolerances, measurement error, measurement accuracy limitations and other factors known to those of skill in the art, can occur in amounts that do not preclude the effect the characteristic was intended to provide. Numerical data can be expressed or presented herein in a range format. It is to be understood that such a range format is used merely for convenience and brevity and thus should be interpreted flexibly to include not only the numerical values explicitly recited as the limits of the range, but also interpreted to include all of the individual numerical values or sub-ranges encompassed within that range as if each numerical value and sub-range is explicitly recited. As an illustration, a numerical range of “about 1 to 5” should be interpreted to include not only the explicitly recited values of about 1 to about 5, but also include individual values and sub-ranges within the indicated range. Thus, included in this numerical range are individual values such as 2, 3 and 4 and sub-ranges such as 1-3, 2-4 and 3-5, etc. This same principle applies to ranges reciting only one numerical value (e.g., “greater than about 1”) and should apply regardless of the breadth of the range or the characteristics being described. A plurality of items can be presented in a common list for convenience. However, these lists should be construed as though each member of the list is individually identified as a separate and unique member. Thus, no individual member of such list should be construed as a de facto equivalent of any other member of the same list solely based on their presentation in a common group without indications to the contrary. Furthermore, where the terms “and” and “or” are used in conjunction with a list of items, they are to be interpreted broadly, in that any one or more of the listed items can be used alone or in combination with other listed items. The term “alternatively” refers to selection of one of two or more alternatives, and is not intended to limit the selection to only those listed alternatives or to only one of the listed alternatives at a time, unless the context clearly indicates otherwise. The term “coupled” as used herein does not require that the components be directly connected to each other. Instead, the term is intended to also include configurations with indirect connections where one or more other components can be included between coupled components. For example, such other components can include amplifiers, attenuators, isolators, directional couplers, redundancy switches, and the like. Also, as used herein, including in the claims, “or” as used in a list of items prefaced by “at least one of” indicates a disjunctive list such that, for example, a list of “at least one of A, B, or C” means A or B or C or AB or AC or BC or ABC (i.e., A and B and C). Further, the term “exemplary” does not mean that the described example is preferred or better than other examples. Similarly, terms, such as “optimize” are not intended to limit embodiments to an optimal approach or result, but rather to express seeking movement toward an optimal result (e.g., to improve, etc.). As used herein, a “set” of elements is intended to mean “one or more” of those elements, except where the set is explicitly required to have more than one or explicitly permitted to be a null set.

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Various changes, substitutions, and alterations to the techniques described herein can be made without departing from the technology of the teachings as defined by the appended claims. Moreover, the scope of the disclosure and claims is not limited to the particular aspects of the process, machine, manufacture, composition of matter, means, methods, and actions described above. Processes, machines, manufacture, compositions of matter, means, methods, or actions, presently existing or later to be developed, that perform substantially the same function or achieve substantially the same result as the corresponding aspects described herein can be utilized. Accordingly, the appended claims include within their scope such processes, machines, manufacture, compositions of matter, means, methods, or actions.

What is claimed is:

1. A method for time-dependent hint generation, the method comprising:

receiving a plurality of resource samples of a child resource by a hinting machine, each resource sample comprising a rendering status of the child resource during a prior rendering of a web page at a corresponding sample time;

determining, by the hinting machine, a time-based probability function using the plurality of rendering statuses of the child resource at the corresponding sample times, the time-based probability function being configured to generate a probability that the child resource will be rendered as part of the web page at a future time relative to a reference time;

calculating, by the hinting machine, a time-based probability of the child resource being fetched as part of a rendering of the web page at a fetching time using the time-based probability function;

applying, by the hinting machine, a decay function to the calculated probability to determine a decayed probability, the decay function being configured to adjust the calculated probability based on an amount of time between the reference time and the fetching time; and generating, by the hinting machine according to the decayed probability, a time-dependent hint for prefetching the child resource,

wherein the decay function comprises a square function.

2. The method of claim 1, wherein the decay function comprises an exponential decay function.

3. The method of claim 1, wherein the decay function comprises a linear function with a predetermined slope.

4. The method of claim 1 further comprising:

receiving a hinting request at the hinting machine from a client machine at a request time in association with the client machine rendering the web page;

generating, by the hinting machine in response to the hinting request, a hinting response comprising the time-dependent hint; and

communicating the hinting response from the hinting machine to the client machine.

5. The method of claim 1, wherein at least some of the resource samples are received by the hinting machine over a communications network from a plurality of different client machines after each of the client machines renders the web page.

6. The method of claim 1, wherein calculating the time-based probability comprises categorizing each resource sample according to a presence model.

7. The method of claim 1, wherein determining the time-based probability function comprises:

determining a freshness of each resource sample; and

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weighting an impact of each resource sample on the time-based probability function according to the freshness of the resource sample.

8. The method of claim 1, wherein the rendering status indicated by each resource sample indicates whether or not the child resource was used during the rendering of the web page at the sample time associated with the resource sample.

9. The method of claim 4, wherein the time-dependent hint is generated based on the request time being used as the fetching time in the time-based probability function and the decay function.

10. The method of claim 4, wherein:

generating the time-dependent hint comprises calculating a plurality of probabilities of the child resource being fetched at a plurality of future times subsequent to the request time;

applying the decay function comprises adjusting each of the plurality of calculated probabilities using the decay function to determine a plurality of decayed probabilities; and

communicating the hinting response comprises communicating the time-dependent hint along with the plurality of decayed probabilities.

11. The method of claim 4, wherein communicating the hinting response further comprises communicating the time-based probability function to the client machine.

12. The method of claim 4, wherein the hinting request indicates a root uniform resource locator (URL) of the web page and the child resource is a child URL of the web page.

13. The method of claim 11, wherein communicating the hinting response further comprises communicating the decay function to the client machine.

14. A hinting machine for time-dependent hint generation disposed in a communications network, the hinting machine comprising:

a sample data store;

a resource sampler that operates to:

receive a plurality of resource samples of a child resource; and

store the plurality of resource samples in the sample data store, each resource sample comprising a rendering status of the child resource during a prior rendering of a web page at a corresponding sample time;

a time-based hint generator that operates to:

determine a time-based probability function using the plurality of rendering statuses of the child resource at the corresponding sample times, the time-based probability function being configured to generate a probability that the child resource will be rendered as part of the web page at a future time relative to a reference time;

calculate a probability of the child resource being fetched as part of a rendering of the web page at a fetching time using the time-based probability function;

apply a decay function to the calculated probability to determine a decayed probability, the decay function being configured to adjust the calculated probability based on an amount of time between the reference time and the fetching time; and

generate a time-dependent hint for prefetching the child resource according to the decayed probability; and

a communications subsystem that operates to communicate the time-dependent hint to a client machine disposed in the communications network;

wherein:

the communications subsystem further operates to receive a hinting request from a client machine over the communications network at a request time in association with the client machine rendering the web page;

the time-based hint generator further operates to generate, in response to the hinting request, a hinting response comprising the time-dependent hint;

the communications subsystem further operates to communicate the hinting response to the client machine;

generating the time-dependent hint comprises calculating a plurality of probabilities of the child resource being fetched at a plurality of future times subsequent to the request time;

applying the decay function comprises adjusting each of the plurality of calculated probabilities using the decay function to determine a plurality of decayed probabilities; and

communicating the hinting response comprises communicating the time-dependent hint along with the plurality of decayed probabilities.

**15.** The hinting machine of claim **14**, wherein communicating the hinting response further comprises communicating the time-based probability function to the client machine.

**16.** The hinting machine of claim **14**, wherein:

the resource sampler further operates to receive: one of the resource samples from a first client machine in association with a prior rendering of the web page by the first client machine; and

another of the resource samples from a second client machine in association with a prior rendering of the web page by the second client machine; and

the second client machine is different than the first client machine.

**17.** The hinting machine of claim **15**, wherein communicating the hinting response further comprises communicating the decay function to the client machine.

**18.** A method for time-dependent hint generation, the method comprising:

receiving a plurality of resource samples of a child resource by a hinting machine, each resource sample comprising a rendering status of the child resource during a prior rendering of a web page at a corresponding sample time;

determining, by the hinting machine, a time-based probability function using the plurality of rendering statuses of the child resource at the corresponding sample times, the time-based probability function being configured to generate a probability that the child resource will be rendered as part of the web page at a future time relative to a reference time;

calculating, by the hinting machine, a time-based probability of the child resource being fetched as part of a rendering of the web page at a fetching time using the time-based probability function;

applying, by the hinting machine, a decay function to the calculated probability to determine a decayed probability, the decay function being configured to adjust the calculated probability based on an amount of time between the reference time and the fetching time; and

generating, by the hinting machine according to the decayed probability, a time-dependent hint for prefetching the child resource;

wherein the decay function comprises a linear function with a predetermined slope.

**19.** The method of claim **18** further comprising:

receiving a hinting request at the hinting machine from a client machine at a request time in association with the client machine rendering the web page;

generating, by the hinting machine in response to the hinting request, a hinting response comprising the time-dependent hint; and

communicating the hinting response from the hinting machine to the client machine.

**20.** A method for time-dependent hint generation, the method comprising:

receiving a plurality of resource samples of a child resource by a hinting machine, each resource sample comprising a rendering status of the child resource during a prior rendering of a web page at a corresponding sample time;

determining, by the hinting machine, a time-based probability function using the plurality of rendering statuses of the child resource at the corresponding sample times, the time-based probability function being configured to generate a probability that the child resource will be rendered as part of the web page at a future time relative to a reference time;

calculating, by the hinting machine, a time-based probability of the child resource being fetched as part of a rendering of the web page at a fetching time using the time-based probability function;

applying, by the hinting machine, a decay function to the calculated probability to determine a decayed probability, the decay function being configured to adjust the calculated probability based on an amount of time between the reference time and the fetching time;

generating, by the hinting machine according to the decayed probability, a time-dependent hint for prefetching the child resource;

receiving a hinting request at the hinting machine from a client machine at a request time in association with the client machine rendering the web page;

generating, by the hinting machine in response to the hinting request, a hinting response comprising the time-dependent hint; and

communicating the hinting response from the hinting machine to the client machine;

wherein the time-dependent hint is generated based on the request time being used as the fetching time in the time-based probability function and the decay function.

**21.** The method of claim **20**, wherein:

generating the time-dependent hint comprises calculating a plurality of probabilities of the child resource being fetched at a plurality of future times subsequent to the request time;

applying the decay function comprises adjusting each of the plurality of calculated probabilities using the decay function to determine a plurality of decayed probabilities; and

communicating the hinting response comprises communicating the time-dependent hint along with the plurality of decayed probabilities.

**22.** A method for time-dependent hint generation, the method comprising:

receiving a plurality of resource samples of a child resource by a hinting machine, each resource sample comprising a rendering status of the child resource during a prior rendering of a web page at a corresponding sample time;

determining, by the hinting machine, a time-based probability function using the plurality of rendering statuses of the child resource at the corresponding sample times, the time-based probability function being configured to generate a probability that the child resource will be rendered as part of the web page at a future time relative to a reference time;

calculating, by the hinting machine, a time-based probability of the child resource being fetched as part of a rendering of the web page at a fetching time using the time-based probability function;

applying, by the hinting machine, a decay function to the calculated probability to determine a decayed probability, the decay function being configured to adjust the calculated probability based on an amount of time between the reference time and the fetching time;

generating, by the hinting machine according to the decayed probability, a time-dependent hint for prefetching the child resource;

receiving a hinting request at the hinting machine from a client machine at a request time in association with the client machine rendering the web page;

generating, by the hinting machine in response to the hinting request, a hinting response comprising the time-dependent hint; and

communicating the hinting response from the hinting machine to the client machine;

wherein:

generating the time-dependent hint comprises calculating a plurality of probabilities of the child resource being fetched at a plurality of future times subsequent to the request time;

applying the decay function comprises adjusting each of the plurality of calculated probabilities using the decay function to determine a plurality of decayed probabilities; and

communicating the hinting response comprises communicating the time-dependent hint along with the plurality of decayed probabilities.

**23.** The method of claim **22**, wherein the decay function comprises a linear function with a predetermined slope.

**24.** A method for time-dependent hint generation, the method comprising:

receiving a plurality of resource samples of a child resource by a hinting machine, each resource sample comprising a rendering status of the child resource during a prior rendering of a web page at a corresponding sample time;

determining, by the hinting machine, a time-based probability function using the plurality of rendering statuses of the child resource at the corresponding sample times, the time-based probability function being configured to generate a probability that the child resource will be rendered as part of the web page at a future time relative to a reference time;

calculating, by the hinting machine, a time-based probability of the child resource being fetched as part of a rendering of the web page at a fetching time using the time-based probability function;

applying, by the hinting machine, a decay function to the calculated probability to determine a decayed probability, the decay function being configured to adjust the calculated probability based on an amount of time between the reference time and the fetching time;

generating, by the hinting machine according to the decayed probability, a time-dependent hint for prefetching the child resource;

receiving a hinting request at the hinting machine from a client machine at a request time in association with the client machine rendering the web page;

generating, by the hinting machine in response to the hinting request, a hinting response comprising the time-dependent hint; and

communicating the hinting response from the hinting machine to the client machine;

wherein communicating the hinting response further comprises communicating the time-based probability function to the client machine.

**25.** The method of claim **24**, wherein communicating the hinting response further comprises communicating the decay function to the client machine.

**26.** A method for time-dependent hint generation, the method comprising:

receiving a plurality of resource samples of a child resource by a hinting machine, each resource sample comprising a rendering status of the child resource during a prior rendering of a web page at a corresponding sample time;

determining, by the hinting machine, a time-based probability function using the plurality of rendering statuses of the child resource at the corresponding sample times, the time-based probability function being configured to generate a probability that the child resource will be rendered as part of the web page at a future time relative to a reference time;

calculating, by the hinting machine, a time-based probability of the child resource being fetched as part of a rendering of the web page at a fetching time using the time-based probability function;

applying, by the hinting machine, a decay function to the calculated probability to determine a decayed probability, the decay function being configured to adjust the calculated probability based on an amount of time between the reference time and the fetching time;

generating, by the hinting machine according to the decayed probability, a time-dependent hint for prefetching the child resource;

receiving a hinting request at the hinting machine from a client machine at a request time in association with the client machine rendering the web page;

generating, by the hinting machine in response to the hinting request, a hinting response comprising the time-dependent hint; and

communicating the hinting response from the hinting machine to the client machine;

wherein the hinting request indicates a root uniform resource locator (URL) of the web page and the child resource is a child URL of the web page.

**27.** The method of claim **26**, wherein the decay function comprises a square function.

**28.** A method for time-dependent hint generation, the method comprising:

receiving a plurality of resource samples of a child resource by a hinting machine, each resource sample comprising a rendering status of the child resource during a prior rendering of a web page at a corresponding sample time;

determining, by the hinting machine, a time-based probability function using the plurality of rendering statuses of the child resource at the corresponding sample times, the time-based probability function being configured to generate a probability that the child resource will be rendered as part of the web page at a future time relative to a reference time;

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calculating, by the hinting machine, a time-based probability of the child resource being fetched as part of a rendering of the web page at a fetching time using the time-based probability function;

applying, by the hinting machine, a decay function to the calculated probability to determine a decayed probability, the decay function being configured to adjust the calculated probability based on an amount of time between the reference time and the fetching time; and generating, by the hinting machine according to the decayed probability, a time-dependent hint for prefetching the child resource;

wherein at least some of the resource samples are received by the hinting machine over a communications network from a plurality of different client machines after each of the client machines renders the web page.

**29.** The method of claim **28**, wherein the decay function comprises an exponential decay function.

**30.** A method for time-dependent hint generation, the method comprising:

receiving a plurality of resource samples of a child resource by a hinting machine, each resource sample comprising a rendering status of the child resource during a prior rendering of a web page at a corresponding sample time;

determining, by the hinting machine, a time-based probability function using the plurality of rendering statuses of the child resource at the corresponding sample times, the time-based probability function being configured to generate a probability that the child resource will be rendered as part of the web page at a future time relative to a reference time;

calculating, by the hinting machine, a time-based probability of the child resource being fetched as part of a rendering of the web page at a fetching time using the time-based probability function;

applying, by the hinting machine, a decay function to the calculated probability to determine a decayed probability, the decay function being configured to adjust the calculated probability based on an amount of time between the reference time and the fetching time; and generating, by the hinting machine according to the decayed probability, a time-dependent hint for prefetching the child resource;

wherein calculating the time-based probability comprises categorizing each resource sample according to a presence model.

**31.** The method of claim **30**, wherein the decay function comprises a linear function with a predetermined slope.

**32.** A method for time-dependent hint generation, the method comprising:

receiving a plurality of resource samples of a child resource by a hinting machine, each resource sample comprising a rendering status of the child resource during a prior rendering of a web page at a corresponding sample time;

determining, by the hinting machine, a time-based probability function using the plurality of rendering statuses of the child resource at the corresponding sample times, the time-based probability function being configured to generate a probability that the child resource will be rendered as part of the web page at a future time relative to a reference time;

calculating, by the hinting machine, a time-based probability of the child resource being fetched as part of a rendering of the web page at a fetching time using the time-based probability function;

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applying, by the hinting machine, a decay function to the calculated probability to determine a decayed probability, the decay function being configured to adjust the calculated probability based on an amount of time between the reference time and the fetching time; and generating, by the hinting machine according to the decayed probability, a time-dependent hint for prefetching the child resource;

wherein determining the time-based probability function comprises:

determining a freshness of each resource sample; and weighting an impact of each resource sample on the time-based probability function according to the freshness of the resource sample.

**33.** The method of claim **32**, wherein the decay function comprises an exponential decay function.

**34.** A method for time-dependent hint generation, the method comprising:

receiving a plurality of resource samples of a child resource by a hinting machine, each resource sample comprising a rendering status of the child resource during a prior rendering of a web page at a corresponding sample time;

determining, by the hinting machine, a time-based probability function using the plurality of rendering statuses of the child resource at the corresponding sample times, the time-based probability function being configured to generate a probability that the child resource will be rendered as part of the web page at a future time relative to a reference time;

calculating, by the hinting machine, a time-based probability of the child resource being fetched as part of a rendering of the web page at a fetching time using the time-based probability function;

applying, by the hinting machine, a decay function to the calculated probability to determine a decayed probability, the decay function being configured to adjust the calculated probability based on an amount of time between the reference time and the fetching time; and generating, by the hinting machine according to the decayed probability, a time-dependent hint for prefetching the child resource;

wherein the rendering status indicated by each resource sample indicates whether or not the child resource was used during the rendering of the web page at the sample time associated with the resource sample.

**35.** The method of claim **34** further comprising: receiving a hinting request at the hinting machine from a client machine at a request time in association with the client machine rendering the web page;

generating, by the hinting machine in response to the hinting request, a hinting response comprising the time-dependent hint; and communicating the hinting response from the hinting machine to the client machine.

**36.** A hinting machine for time-dependent hint generation disposed in a communications network, the hinting machine comprising:

a sample data store;

a resource sampler that operates to:

receive a plurality of resource samples of a child resource; and

store the plurality of resource samples in the sample data store, each resource sample comprising a rendering status of the child resource during a prior rendering of a web page at a corresponding sample time;

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a time-based hint generator that operates to:  
 determine a time-based probability function using the plurality of rendering statuses of the child resource at the corresponding sample times, the time-based probability function being configured to generate a probability that the child resource will be rendered as part of the web page at a future time relative to a reference time;  
 calculate a probability of the child resource being fetched as part of a rendering of the web page at a fetching time using the time-based probability function;  
 apply a decay function to the calculated probability to determine a decayed probability, the decay function being configured to adjust the calculated probability based on an amount of time between the reference time and the fetching time; and  
 generate a time-dependent hint for prefetching the child resource according to the decayed probability; and  
 a communications subsystem that operates to communicate the time-dependent hint to a client machine disposed in the communications network;  
 wherein:  
 the communications subsystem further operates to receive a hinting request from a client machine over the communications network at a request time in association with the client machine rendering the web page;  
 the time-based hint generator further operates to generate, in response to the hinting request, a hinting response comprising the time-dependent hint;  
 the communications subsystem further operates to communicate the hinting response to the client machine; and  
 communicating the hinting response further comprises communicating the time-based probability function to the client machine.  
**37.** The hinting machine of claim **36**, wherein communicating the hinting response further comprises communicating the decay function to the client machine.  
**38.** A hinting machine for time-dependent hint generation disposed in a communications network, the hinting machine comprising:  
 a sample data store;  
 a resource sampler that operates to:  
 receive a plurality of resource samples of a child resource; and

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store the plurality of resource samples in the sample data store, each resource sample comprising a rendering status of the child resource during a prior rendering of a web page at a corresponding sample time;  
 a time-based hint generator that operates to:  
 determine a time-based probability function using the plurality of rendering statuses of the child resource at the corresponding sample times, the time-based probability function being configured to generate a probability that the child resource will be rendered as part of the web page at a future time relative to a reference time;  
 calculate a probability of the child resource being fetched as part of a rendering of the web page at a fetching time using the time-based probability function;  
 apply a decay function to the calculated probability to determine a decayed probability, the decay function being configured to adjust the calculated probability based on an amount of time between the reference time and the fetching time; and  
 generate a time-dependent hint for prefetching the child resource according to the decayed probability; and  
 a communications subsystem that operates to communicate the time-dependent hint to a client machine disposed in the communications network;  
 wherein:  
 the resource sampler further operates to receive:  
 one of the resource samples from a first client machine in association with a prior rendering of the web page by the first client machine; and  
 another of the resource samples from a second client machine in association with a prior rendering of the web page by the second client machine; and  
 the second client machine is different than the first client machine.  
**39.** The hinting machine of claim **38**, wherein:  
 the communications subsystem further operates to receive a hinting request from a client machine over the communications network at a request time in association with the client machine rendering the web page;  
 the time-based hint generator further operates to generate, in response to the hinting request, a hinting response comprising the time-dependent hint; and  
 the communications subsystem further operates to communicate the hinting response to the client machine.

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